WESTERN UNION
UNION
Technical Review

A Self-Regulating Multiplex

•

Multiplex Operation

•

Switching System Maintenance

•

Vestigial Sideband
Transmission

•

Telegraph Training Center

•

Voiceband Equipment
for Microwave Telegraphy

WESTERN UNION
Technical Review

CONTENTS

INDEX

For contents of Technical Review's
published previous to 1958, see
separately printed Index for
1947 — 1957

HAROLD F. WILDER, Assistant to Electronics Applications Engineer

A Self-Regulating Multiplex

The time-division concept of multiplex transmission systems, although mentioned recently as an idea which is new and subtle in voice transmission, is by no means new to telegraph engineers. Western Union specifications 263-C of 1926 covering theory and operation of a multiplex printing telegraph system were as notable as any ever issued by the company. Today, electronic technology offers a contemplated but as yet untested method to create a new multiplex printing telegraph system with promise of automatic synchronization.

THERE is always a latent possibility that the signalling capability of a telegraph circuit can be increased and like a game of chess this presents an intellectual challenge to the communications engineer. The familiar narrow-band carrier channel is an intriguing subject for scrutiny and while acknowledging that economic considerations rather than technical adroitness will dictate the extent of its usefulness, this article proposes to discuss the ascendancy of start-stop signalling and from that basis to suggest a new multiplex. The proposed system would retain the operational flexibility of a teleprinter facility but enjoy the efficient use of bandwidth characteristic of time-division telegraphy. Appropriately applied, the concept will approximately double the traffic space of narrow-band frequency-divided carrier telegraph channels.

In multiplex operation the necessity to channel-phase the synchronous receiving distributor and to orient correctly the point of signal selection implies dependence upon skillful technicians at the terminals. Coupling successive line sections with regenerative repeaters only emphasizes the reliance on human intervention either when starting a circuit or when restoring loss of synchronism. On the other hand, the teleprinter signal idea, for the price of bracketing the intelligence impulses by start and stop pulses, has boldly eliminated supervisory requirements and permitted the telegraph to enter the small office and business house.

When the teleprinter circuit is idle the armature of the receiving selector magnet is held operated by the steady marking current in the unipotential single connect-ing line circuit. Although quiescent the teleprinter is in a receptive condition and upon the arrival at any moment of a start pulse the armature is released, causing a clutch instantly to engage an assembly of five sequential cams with a continuously rotating main shaft. The five cams then scan the five intelligence impulses and set up the code bars of a mechanical matrix that actuates the typelever. The clutch is then disengaged and the cam assembly comes to rest. Because the cycle is repeated for each character the time phase of the receiving selector cams needs but approximate synchronism with the incoming signals for the duration of a single character hence the frequency stability of the public utility driving the teleprinter motor is usually adequate.

Crystal Frequency Control

Reflection suggests that if the frequency sources governing the rate of character emission, and reception, possessed the frequency stability of a crystal-controlled oscillator, transmission could be spaced in discrete bursts of a minute's duration, each prefixed by a starting code-group and terminated by a short rest interval. Within the burst the system could be operated as a multiplex and the frequency space previously occupied by the start and stop pulses made available for the transmission of additional intelligence.

Operation on a time-division basis during the burst is possible, however, only if a further qualifying condition can be satisfied. A subtle deficiency of the teleprinter signal is the dependence of intelligence impulse selection upon the arrival

time of the start-pulse wavefront. If, because of bias or distortion, for example, the latter is delayed with respect to the instant corresponding to an undistorted condition, the clutch will be engaged later than is proper and all subsequent impulse selections for that character will be retarded in time-phase. Since the intelligence bits are equally susceptible to distortive effects the "printing range" is reduced. The same result obtains for an advance of the start pulse. The more sophisticated synchronizing circuitry of a time-division telegraph, however, insures that the polarity of the signal impulses will be determined at the center of their mean time of duration irrespective of distortion. In effect not one but all signal transitions contribute to the determination of an average arrival time, and consequently the synchronous telegraph can withstand twice the distortion accepted by a start-stop character. If the self-regulating multiplex is to possess the operating self-sufficiency of a teleprinter and yet exhibit the robustness of the synchronous telegraph in the presence of signal malformation, the receiving terminal of the proposed multiplex must possess automatic means acting on the integration of several signal transitions to reorient or "range" signal selection at the beginning of each burst of transmission. As a by-product, minute by minute automatic signal ranging will absorb the inevitable small frequency differences developing between the sending and receiving crystal-oscillators, thereby eliminating the all too familiar "corrector" of synchronous telegraphs.

Modern electronic technology makes the self-regulating multiplex concept practicable but before embarking upon a description of its parts, a review of the known performance of narrow-band carrier channels supporting time-division circuits will establish the maximum target.

In the frequency-modulated carrier system of The Western Union Telegraph Company the individual telegraph channels derived by frequency division from a voiceband are spaced at intervals of 150 cycles. Abroad, and on the transatlantic telephone cable, the spacing is 120 cycles.

The latter may be modulated at the rate of 80 impulses per second and one might infer that channels spaced at 150 cycles will carry a baud rate of 100. Indeed, for some years several three-channel multiplexes have been operating at 100 bauds over single carrier sections between ocean cable landings and inland terminals. And recently three-channel multiplexes at 75 bauds show outstandingly good performance on telephone cable telegraph circuits.

With this experience setting a practical limit for the new concept, a self-regulating multiplex funnelling two 75-word teleprinter circuits through a domestic narrow-band carrier channel will be described.

THE SENDING TERMINAL

Two requirements determine the number of multiplex operations per minute. The incoming teleprinter circuits of nominal 75-word speed actually operate at 460 characters per minute but because the frequency of the public utility driving the motors may vary up or down by perhaps one cycle per second for short periods, good practice requires that the multiplex run about two percent, or nine operations, faster if the transmitting capability of the latter is always to exceed incoming traffic from the extensions. The second requirement evolves from the remark in the preamble that a rest operation will conclude, and a starting and alignment operation precede each burst of transmission. A total of 471 operations per minute are thus required.

Calculation of the multiplex baud rate is contingent upon a further consideration. Until recently only five intelligence impulses per character would have been involved but with present day data and enciphered traffic containing information-bearing BLANKS it becomes necessary to distinguish between them and the systemic blanks emitted by an idling multiplex channel. Of several methods the addition of a sixth impulse to every character group provides an elegant way to "flag down" the systemic blank since a distinctive polarity for this impulse can

then cause the receiving multiplex to hold the teleprinter extension closed. Consequently the baud rate of the sending two-channel multiplex becomes $2 \times 471 \times 6 \div 60$ or 94.2 impulses per second, each of 10.6 milliseconds duration.

sistor chain stepping impulses at the baud rate of the multiplex or 94.2 per second, so that the latter cycles through its two six-impulse channels 471 times per minute. Other associated components are displayed in Figure 1 and their individual
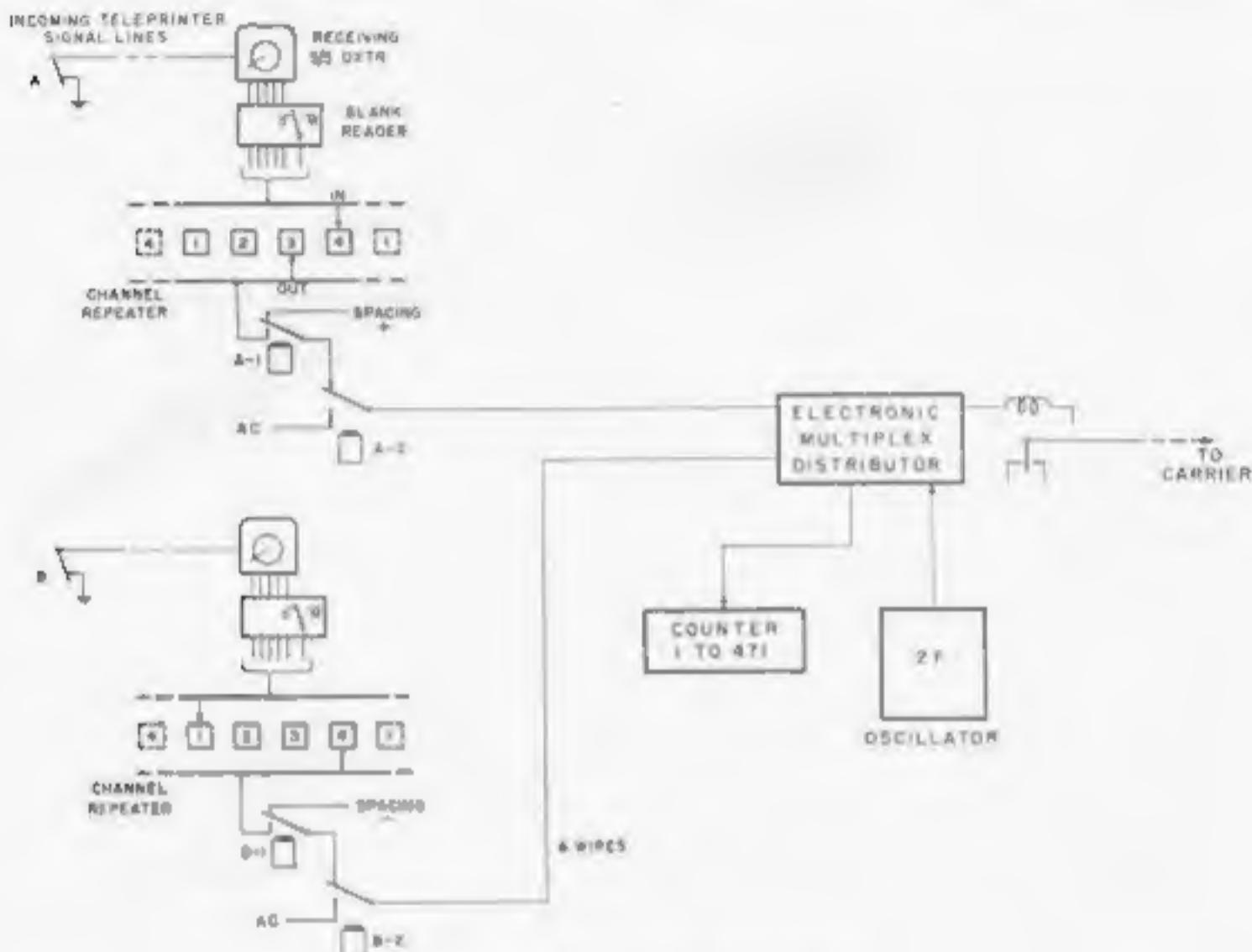

Figure 1. Sending terminal block diagram

(While 94.2 bauds is quite acceptable to a narrow-band carrier channel on domestic systems of 150-cycle spacing it exceeds the capability of those of 120-cycle spacing. In transatlantic service, therefore, the design would be restricted to two 60-word circuits at a speed of 368 operations per minute, and the baud rate then becomes $2 \times (368 + 7 + 2) \times 6 \div 60$ or 75.4 impulses per second.)

Chain Stepping Pulses

The basic component of the sending terminal is a crystal-controlled frequency source generating by subdivision tran-

circuitry is well known. The system is shown with both teleprinter lines closed and the multiplex chain idling but continuously sending alternations composed of six positive impulses for A channel and six negative for B channel. It might be presumed that growth of apparatus bias will be inhibited by the transmission of continuous channel reversals during circuit idle time.

Upon the reception of a teleprinter character the start-stop distributor will deliver the five intelligence impulses to whatever storage tank the input fingers are at that time connected. Just before the distributor comes to rest it develops an auxiliary pulse to advance the input

fingers to the next tank of the ring, so opening the gap between the input and output fingers, a condition that is quickly sensed by the idling multiplex chain which then starts the counter. On its first step the counter, assisted by pulses from the multiplex, causes relays A-2 and B-2 to operate in channel sequence and a series of six reversals called the starting and alignment code-group is sent to line to start up the distant receiver. During subsequent operations of the counter up to number 470 the relays A-2 and B-2 are released and relays A-1 and B-1 are operated so that information stored in either channel repeater is sent to line. Occasionally the multiplex will catch up to the input of a channel repeater and will pause long enough to send a systemic blank identified by a sixth impulse of spacing polarity, or send systemic blanks continuously if the respective channel extension becomes idle. An enciphered blank will have its sixth impulse of marking polarity.

At the conclusion of the 470th operation relays A-1 and B-1 are released and during the 471st operation a channel reversal is sent to line. If no traffic waits in either channel repeater, channel reversals continue indefinitely; if traffic is still stored in the tanks the cycle will be repeated, preceded, of course, by the six reversals constituting the starting and alignment signal.

Figure 2 charts the timing before and after the transmission of the starting sig-

Figure 2. Starting and ranging signals

nal. Both extensions were assumed idle prior to this time and transmission had lapsed into continuous channel reversals of which the last pair m and n would have

been sent even if traffic had been waiting in either channel repeater. In the figure, one must assume that intelligence was received from the B-channel extension during the time m; if received during n another channel reversal would have been sent before the six reversals would have been released. Apparently the letter R initiated operation in this case followed by an encoded blank, and so on. It so happens that about this time traffic began on the A channel for the letter J appears but since the burst has started there is no need for sending an alignment signal.

THE RECEIVING TERMINAL

When the system is idle the receiving multiplex electronic distributor of Figure 3 is at rest and the teleprinter extensions held closed. Incoming channel-reversals, however, are scanned continuously in anticipation of the next starting and alignment signal whose time of arrival is, of course, quite uncertain. The impulses s, z, e, 1, 2, 3, a—h of Figure 2 derived from receiving relay transitions are fed to the start signal counter and timer to effect this recognition but to the exclusion of spurious "hits" or "opens" on the facility. Only if the counter is advanced four steps by a correct sequence of polarized impulses prior to the time t will the timer cease to reset the counter and instead connect the signals through relay R-1 to the ranging circuitry.

Ranging impulses a to h are devoid of characteristic distortion and their arrival instants depart from multiples of bit time only because of apparatus bias or noise effects and whatever drift has built up between the free-running sending and receiving oscillators since the previous burst of transmission. It is the function of the ranging circuitry to match each arrival instant with one of 20 separate phases of the receiving oscillator and from this weighted information to develop a new phase representative of the average arrival time of the eight impulses. The new phase then positions the signal selection gates during the following burst of transmission just as if a "range" had been taken and centered manually on test slip.
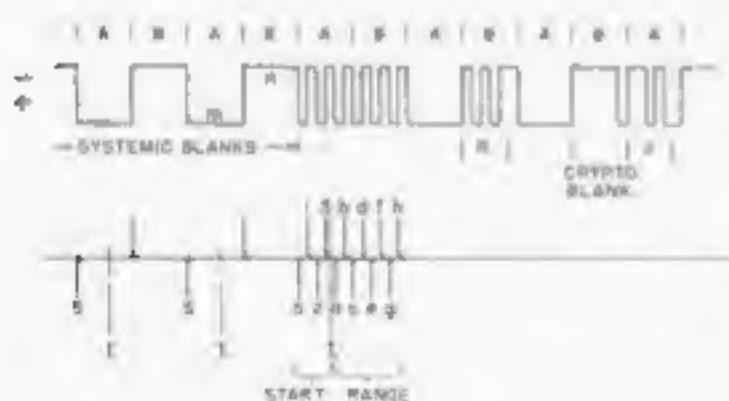
An oscillator, 2F, is the station frequency source for both sending and receiving apparatus. The frequency is very closely that of the multiplex baud rate, or one cycle per signal impulse, and for the system being described 94.2 cycles per

uted over several slots in the vicinity of the undistorted condition. In any event each coincidence will step a counter associated with each slot whose function is to measure the relative frequency of occurrence. For each count, up to perhaps a
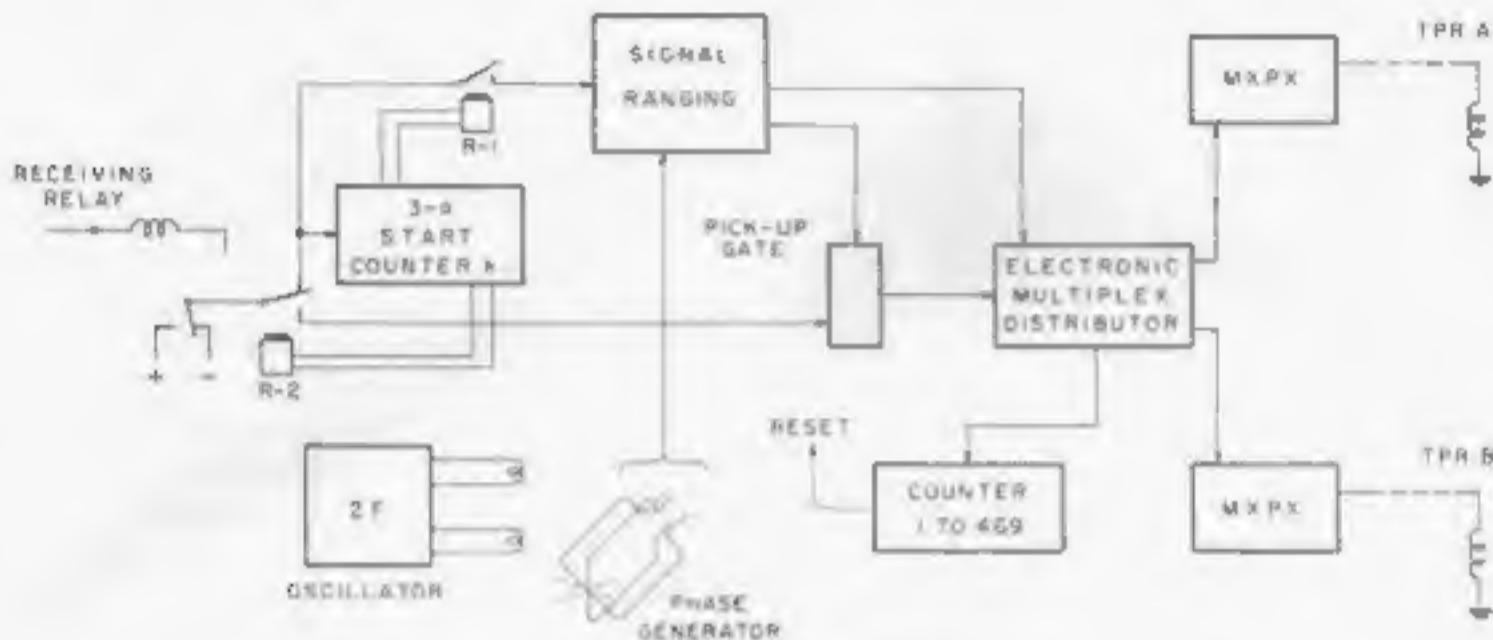

Figure 3. Receiving terminal block diagram

second. Old hands will see similarity to the fork regenerative repeaters of a few decades ago. The 20 phases are generated by a modified Drysdale phase shifter whose rotatable armature is replaced by a fixed core supporting ten equiangular windings. Two separate stator windings are orthogonally disposed and excited by quadrature currents from the oscillator. The resultant magnetic field sweeps around the windings once in signal bit time generating alternating voltages with phase differences of 36 degrees. Each phase drives a transistor flip-flop to "square up" the alternations. A high resistance couples successive but opposite transistor collectors in the ten-stage ring and the midpoints of the resistors show voltage impulses of short duration that provide 20 coincidence gates during each undistorted signal impulse.

Signal Distortion

If the signals are distortionless the eight transitions a to h will fall in a single slot; in the presence of distortion many will be delayed or advanced and will be distrib-

maximum of four, an alternating voltage of unit amplitude from the respective phase is fed to a summation amplifier whose output becomes the vector sum of unit voltages from the coincidence gates. Because the voltages are added vectorially the angle of their resultant will be very nearly in phase with the center of the average signal and may be used to open momentarily the pickup gates to effect regeneration of the signals passed to the multiplex receiving distributor. Stability of the sending and receiving oscillators insures that signal selection will drift away but a negligible amount during the following minute's burst of transmission.

Figure 4 displays alignment signals randomly displaced in time by noise currents that cause the shifting transitions to fall in slots on and to either side of the undistorted times of incidence. With automatic ranging the vector sum of the eight incremental voltages taken at their slot angles is the resulting E_s. Crossing of the zero axis by $-E_s$, the negative slope of this voltage, opens the pickup gate at the time A, very nearly coincident with the signal center. A manually centered range

midway between the latest and earliest transitions, at point M, comes off second best for this particular series of events. Biased signals develop two slot voltages, one advanced, the other delayed by an equal angle. Their vector sum also will
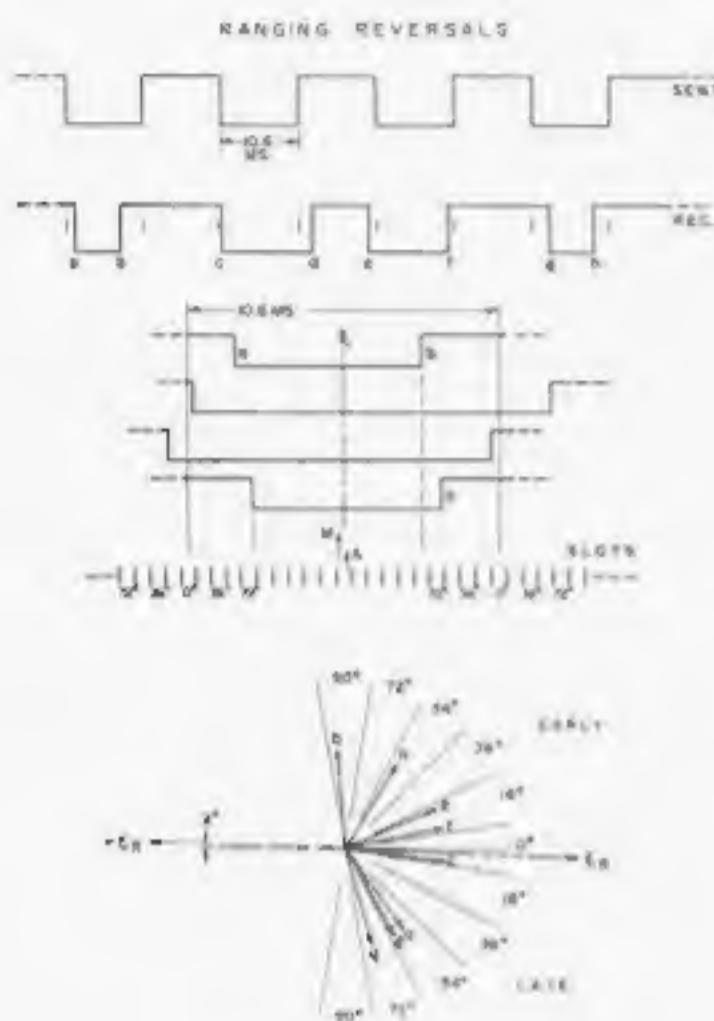

Figure 4. Ranging theory

scan centrally both marking and spacing signal impulses.

After 12 counts (transition h) the start signal counter activates the multiplex receiving chain and diverts the signal input to the pickup gate through relay R-2. For each operation of the multiplex distributor the main counter advances one step

until at number 469 all operations cease and the counters are restored to zero in readiness for the next burst of transmission. In the course of the 469 operations, the five intelligence impulses of each channel are distributed to their respective multiplex to teleprinter signal translators, MXPX, and reconstituted with start and rest pulses for transmission to the extensions. Systemic blanks are deleted; enciphered blanks are released to the extension under control of the sixth code pulse.

Although teleprinter characters are emitted by the MXPX at the rate of 471 characters per minute the start and intelligence impulses are of the correct length, 17.57 milliseconds, for operation of 75-word printers. The accommodation is effected by a shortening of the rest pulse from 25 to 22 ms. In any minute of time the actual number of characters released to the extension is still 460, and systems of this description can be cascaded without limit.

*   *   *   *   *

This concept is not restricted to the combination of two teleprinter circuits; it's not inconceivable that a single but unusually high-speed circuit might be encountered whose marginal operation could be corrected by conversion to time division. In retrospection, however, the apparatus for either single or multichannel systems will not be inexpensive and will probably be incapable of competing with the cost of an additional narrow-band channel. Of possible applications, long hauls of 1000 miles or submarine cable operation may provide sufficient savings to justify the development and installation expense.

A biographical sketch of the author appears in the January 1957 issue of Technical Review.

RONALD S. WISHART, Assistant Project Analysis Engineer

Some Views on Multiplex Operation in Western Union

Downfall of the Multiplex Empire that flourished in the 1920's was brought about by a combination of circumstances. Important contributing factors included development of "simplex" start stop teleprinters, evolution of carrier telegraph transmission systems and improvements in reperforator switching methods. Nevertheless, a resurgent time-division "mux" or some more efficient spectrum divider, it has been said, may in turn replace the start-stop frequency-division mode.

FORTY-FIVE years ago Western Union started to use synchronous time-division multiplex on physical open wire plant and circuits so operated became a network covering the whole country. One wonders why, by the year 1959, its use has been reduced to less than 26 percent of trunk channels in public message operations and to substantially zero in private wire service.

Why has start-stop teleprinter on 150-cycle carrier channels so largely taken the place of multiplex, and is there likelihood for again increasing use of multiplex?

Circuit Arrangements

The Western Union multiplex, when used on open wire physical facilities with ground return, overcame considerable disturbance of various types and provided by time-division as many channels as were permitted by duplex balance methods and repeater spacing. Two-, three- and four-channel multiplexes outmoded Morse quadruplex operation and were economically superior to the single channel printer circuits that preceded them. Based on fork series operation ("drop channels" in Postal Telegraph Company), regeneration and multiplex start-stop repeaters, a network of channels was created throughout the country which handled public message traffic at a nominal speed of 65 wpm. In addition, varioplex subchanneling made variable speed channels available for customer use as well as for Western Union. In this period of growth there were numerous relay cities picking up the traffic from smaller towns in their areas and forwarding the messages to other relay points or destinations. There were 161 such relay offices in this category in 1946.

Three programs intruded upon the empire of multiplex, namely:

(a) Development of start-stop keyboard teleprinters, starting in 1922

(b) Application, starting about 1921, of telegraph carrier to paired Western Union physical wires or leased voice-bands and, latterly, radio beam circuits.

(c) Reperforator switching, which reduced the number of relay offices from 161 to 15

The start-stop keyboard teleprinters started as 40-word-a-minute tape printers about 1922 and later became 60- to 65-wpm machines of both tape and page form. They began to be used in customers' offices for tie-line connections to central offices of the telegraph companies and between branch offices and central offices. Because of their small size and relative simplicity they came into use as inter and intra private company communication devices aside from their public message uses. In the 60-65-word-per-minute form, they were used on extended legs of multiplexes by introducing multiplex start-stop repeaters.

By 1933 the start-stop teleprinter to which Western Union made significant design contributions had grown up enough to become part of a teletypewriter exchange service which has expanded into a

country-wide system. Paralleling this growth there has been a tremendous increase in the number of circuits and switching systems leased to customers by Western Union and others, for it does not take very much TWX service between two points to pay for a lease line. These systems have grown up free of the restrictions that would have been put upon them if development had been forced into the strait jacket of multiplex channels. Many of the control systems in public message and private wire service are not compatible with multiplex operation.

Over the years developments and improvements produced teleprinters and auxiliary devices such as tape transmitters, printer-perforators and perforators capable of 75 wpm, 100 wpm and higher speeds.

Influence of Carrier

The introduction of frequency-modulated carrier on metallic pairs produced relatively disturbance-free channels. At first the channels were designed for bands spaced 300 cycles apart and each carried four-channel multiplexes at 65 words per minute per channel.

Later, the demand for more channels that could be used for customer purposes with start-stop units requiring only a small portion of a 300-cycle band, resulted in Western Union standardizing on channels spaced 150 cycles apart. The Bell System adopted 170 cycles and European administrations standardized on 120 cycles.

The Western Union radio beam system which is now providing carrier telegraph channels is also substantially free from atmospheric and multipath effects since it is designed for telegraph operation with space diversity reception in the older installations and frequency diversity in the newer installations. While there are some residual multipath and fading effects during periods in summer, they occur after midnight, have usually cleared by 8 a.m., and have slight effect during business hours.

The Western Union program of development and engineering on carrier terminal equipment has been very successful in that improvements have kept the capital cost per carrier channel from rising for 20 years and simultaneously reduced the annual costs. The original Type 15 carrier required five square feet of floor space per channel and the latest, the Type 60, requires less than three quarters of a square foot per channel while the power requirement has been reduced to a fifth of that of the original channels. Transistors and other solid-state devices have reduced maintenance requirements for replacing vacuum tubes and for minor repairs. Air conditioning demands are much reduced.

By June 1959 Western Union had in operation some 3,816,000 miles of telegraph carrier channels, of which 541,000 are on radio beam providing a relatively disturbance-free system; therefore, multiplex operation as a means of overcoming disturbance no longer has its original degree of importance.

Elimination of Relaying

The program of reperforator switching centers in public message service wiped out the need for the extensive and complex multiplex network joining 161 relay centers and such multiplex as remained became point-to-point. Developments such as Plan 34[1] and page reception from trunks[2] require 77 words per minute per channel and are beyond the capacity of multiplex channels on 150-cycle telegraph carriers. Signalling systems in use on tributary extensions from Plan 21[3] switching centers do not fit multiplex operation. For these and other reasons multiplex operation is fast being limited to circuits between public message switching centers. It is still claimed, however, that synchronous multiplex will squeeze a little more out of the 150-cycle frequency band and should, therefore, be attractive for that reason.

Let us examine this situation for a moment. Table I compares the number of communication circuit sections that can be operated safely in tandem at different frequencies and words per minute before regeneration is necessary. Sections in this

case include other types of facilities besides carrier channels.

TABLE I

Channel WPM	Code Units Per Ca.	Keying Freq.	Sections without Regen.	Type of Equip.
65	7.0	22 75	6	Start-stop
75 (76.7)	7.42	27.82	5	Start-stop
100	7.42	37.1	3	Start-stop
*66x2	5.0	33.0	4	2-ch. mux
*66x2	6.0	39.6	2	2-ch. mux

*132 words total per multiplex

The greater number of sections covered by start-stop has been of more interest than more efficient use of sections by multiplex because of the very large number of short length sections into which the Telegraph Company's facilities are divided in the private wire service There are only a few cases where there are enough parallel channels over a long haul to justify consideration of some form of multiplex. Regeneration is an accepted and desirable procedure for reproducing good signals in following sections of a circuit and in no sense are these comments a criticism of the method. However, it is true that present electronic regenerative

repeaters add a cost equal to that of an ordinary carrier channel terminal and their maintenance cost is greater in hours per year than that of the channel terminal. It therefore seems sensible to avoid the investment where other circuit arrangements are equally satisfactory and less expensive. Of course many large networks cannot possibly be worked without regenerative repeaters.

Distribution of Circuit Sections

Most advocates of multiplex feel that it should be used on long haul circuits. A review of the possibilities of this in Western Union plant is shown in Figure 1 This graph consists of four pie charts, three of them for private wire service sections, and one for teleprinter trunks between switching centers in public message service. The three PWS charts cover 65-wpm, 75-wpm and 100-wpm teleprinter sections respectively, distributed by mileage. The analysis of PWS sections was made in August 1959 and contains all sections in route miles between point-to-point terminals or between way-station points as the case may be. No local loops or items in that category are included One newspaper press association system was left out of the listing in 1959. The

Figure 1   Route mile sections between terminals and/or way points by mileage — distribution according to section length

summary below gives totals of private wire service sections in 1956 and 1959 and public message sections in 1958.

SUMMARY OF CIRCUIT SECTIONS

WPM	PWS		Public message service (interswitching centers)
	1956	1959	1958
65	5584	7847	208
75	709	1939	
100	471	611	
	6764	10,397	208

NOTE The 1956 and 1959 figures are roughly comparable, though the former may not contain as many intrastate sections as the 1959 figures. The difference in basis is small, however

The charts show that the great preponderance of sections in private wire service are short, and the summary of circuit sections indicates that 75- and 100-wpm sections combined are now growing in number at a faster rate than 65-wpm sections.

The distribution in these private wire service charts shows remarkably few sections of any considerable length that would justify a multiplex of some design to provide operation. The chart for public message service trunks will be considered further along in this discussion

Multiplex and Way Stations

The short sections in private wire service are normally associated to make up way wires which may have three to 18 stations. To reduce the need for regeneration all stations are usually reached by keeping the number of sections from a switching center down to a point where they do not exceed the number of sections in Table I. This means that way wire may branch out as a number of carrier or physical legs at the first way point and similarly at other points so that all receiving points are served within the limits of six sections for 65 wpm and by fewer sections at other speeds. The duplex way circuit becomes quite complex since the sending legs from the outstations couple into the trunk to the switching center through "hubbing" or similar repeaters.

Multiplex applied to such Christmas-tree formations of way wires is uneconom-ical. One channel would have to be carried through the whole network to maintain synchronism while the second channel passes through station equipment at each way station. There would be full regeneration at each station but not much economic value would be gained from the synchronism controlling channel because it is unlikely to be needed at points where it is available.

The specifications for a multiplex that might be applicable to private wire service include several items that are not requirements for public message service, such as:

(a) The multiplex must delete blanks produced in the idle condition or when slippage occurs between signals on the incoming start-stop leg and the synchronous transmission of the multiplex, and hold the start-stop lines on marking. It must not delete blanks originating in the start-stop transmission. It must pass open line signals from the entering start-stop line as a series of blank signals, converting them to open line signals on any start-stop extension, for selector control.

(b) The multiplex must be self-rephasing if a circuit interruption or any other accident causes it to go out of phase.

(c) It is suggested that it be completely electronic to keep its cost down.

Present designs of mechanical and partially electronic two- to four-channel multiplexes have within the last ten years risen in cost to a point where they are out of the running for land-line use.

Transmission of Blanks

A proposed electronic multiplex studied at Western Union Water Mill Laboratories was a 6-unit multiplex with the sixth unit used to determine when signals originating on a start-stop source of transmission should be passed through the multiplex and repeated into the start-stop extension. Correspondingly any blank originating in the mux channel itself should be deleted by a negative state of the sixth unit.

Need for the transmission of blanks is the result of the large amount of en-

crypted government traffic passing over PWS systems. This encryption, either off-line or on-line, produces "blanks" as one of the characters.

In the cable system where the 5-unit multiplex must be retained to get the best out of the frequency spectrum available over very high cost facilities, this problem of handling "blanks" has in one case been met by causing a blank to be read as an X in a reperforator-transmitter entrance to the multiplex channel.[1] A regular X is sent as MX and M is sent as MM. At the distant end of the cable the X is translated as a blank. The M is dropped in MX and an M in MM is dropped. This is too expensive a method to consider with landline facilities which are relatively low in cost, hence the use of 6-unit code. It is difficult to make a multiplex instantly self-phasing in event of an accident that throws it out of phase because rephasing is usually designed to occur when one channel is momentarily idle, and as a result quite a few mutilated characters may be transmitted on both channels before the multiplex falls back into correct operation. A start-stop unit tends to correct itself more rapidly and the trouble usually occurs as part of the terminal operation where it is readily understood. There is a strong suspicion even such a self-phasing multiplex would create trouble reports, the reason for which would be difficult to find when the multiplex channels form a section of a PWS circuit network with start-stop extensions. Also suppose that a customer at the end of a start-stop extension reports garbled reception and by the time the report gets back to the technical supervision people along the circuit, rephasing has occurred and no apparent cause for trouble is found. This may not happen very often but it could be irritating and troublesome to both the customer and the Telegraph Company

Multiplex vs. Teleprinter on Way-Wires

Figure 2 shows the increase in cost as a result of using two multiplex channels rather than two teleprinter channels vs. circuit length. Of the two channels in each pair one is a 6-section way wire and the

other is a direct circuit along the same route and equal in length to the total mileage of the 6-section way wire. Cost of the equipment for one multiplex terminal is assumed to be $2000 installed without any proportionate share of development
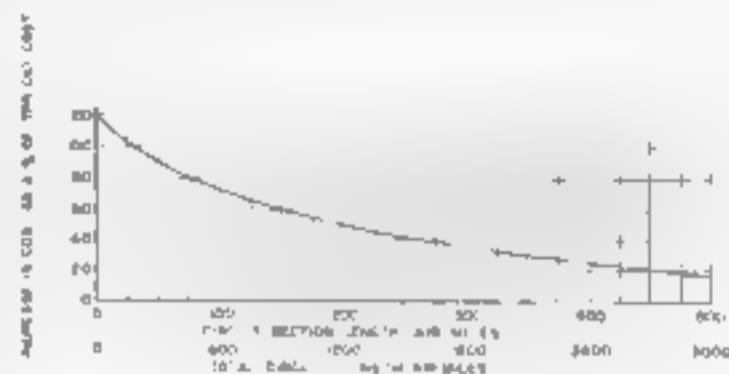

Figure 2. Multiplex vs. teleprinter on way wires

and engineering charges. When six way sections each 500 miles long and requiring multiplexes back to back at each station are used, the multiplex cost is 16 percent higher than that of the two teleprinter circuits. It is much higher for shorter section lengths.

Figure 3 compares results when using two multiplex channels rather than two
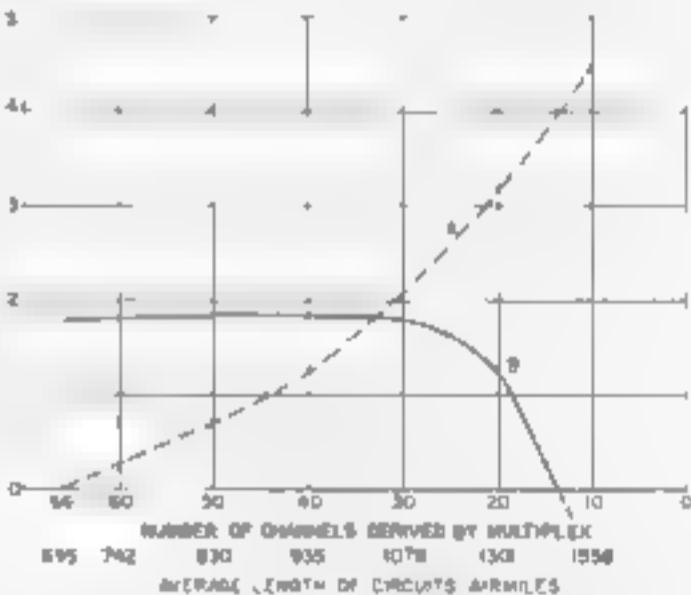
Figure 3. Benefit or loss resulting from applying two-channel multiplex on one carrier channel vs. using two carrier channels

teleprinter channels for point-to-point use vs. circuit length. The sample upon which this study is based consists of 66 channels, out of the number shown on Figure 1 between Western Union switching centers, which seem susceptible of conversion to multiplex. Two curves are shown, A being

based on the estimated present installed cost, $4300, of the existing 67A multiplex with multiplex start-stop repeaters added to make it comparable with the multiplex on which curve B is based. The B curve represents the multiplex just described, that does not exist but might be built and installed for a cost of $2000 per terminal plus capitalization of research and engineering expenditures in proportion to the number of installations made. In this curve the loaded development and applied engineering expenditures of roughly $75,000 have been amortized on a 14-year life basis as part of annual charges. Interest was not included in annual charges in either A or B curves. The curves show return on investment after taxes. Curve A shows a better return than B for the long-haul first 30 channels, but it is not as good as B in the aggregate. Neither curve shows sufficient return on investment to support multiplex installation.

Operating Speeds

So far nothing has been said about speed of operation in words per minute that will be required in private wire service. Figure 1 showed a preponderance of 65-wpm sections and a moderate number of 75-wpm and 100-wpm sections. The discussion which follows Figure 1 indicates that the higher speed sections are now growing in number faster than the 65-wpm sections. In 1957 Western Union commenced purchasing Type 28 teleprinter equipment in large quantities and it is all capable of 75- or 100-wpm operation. One installation alone has added 145 sections at 100-wpm speed. There have been other installations and several large ones are being made now. The trend is definitely toward 75- or 100-wpm operation, because more stations can be placed on a way wire, reducing the number of way wires and reducing the number of positions in switching centers. The premium paid by customers for the high speed of these circuits tends to be well offset by reductions in circuit mileage and central office switching equipment.

All start-stop printers under design are to be capable of 100 wpm and higher

speeds. This definitely imposes a dilemma when one considers use of multiplex channels as a vehicle for such start-stop circuits. A 6-unit multiplex could operate at 66 wpm with a signal frequency of 39.6 cycles or about the safe top limit for 150-cycle carrier channels. This multiplex would be obsolete for 100-wpm speeds before it could be developed. If it is considered for existing 65-wpm start-stop operation the other horn of the dilemma is encountered, i.e., many customers' stations are equipped with instruments capable of 75 and 100 wpm though operated at 65 wpm and with increasing loads they can ask for speed changes out of range of the multiplex.

Consideration is being given to carrier channels of 300 cycles and wider for single channel data transmission. These do not require further channelizing for the purpose for which they are being designed but could be used for higher speed multiplexes if desired. The idea does not appear enticing, however, as it certainly isn't efficient to have several fixed speed networks (such as would exist if they were provided by multiplexes) as opposed to a common pot consisting of a network that can be utilized interchangeably for 65, 75 and 100 wpm, and perhaps two networks, one of which will allow 240 wpm and the other the full voiceband.

A problem to be faced in the higher speed range is the variety of data transmissions originating from various business machines. These transmissions have not been standardized as to speed, rest pulses, intelligence pulse lengths, and so forth. Here synchronous operation if not multiplex might well come into use provided the business machine codes are standardized to even length pulses. With speeds also standardized this would simplify regeneration of signals and tests for distortion.

In this discussion historic forms of multiplexes fitting the company's normal channels have been considered, and discussion of more sophisticated large capacity types of multiplexes has not been ventured upon because consideration of them seems hardly justifiable now in a system such as Western Union's which has

Ronald S. Wishart acquired his education in Scotland, France, England and the United States. Entering the service of the Postal Telegraph Company in 1907, he served as printer attendant and later as Automatic Chief Operator in New York. With the introduction of Morkrum apparatus in the Associated Press, he became Chief Operator in that service. During World War I he served with the Signal Corps in Europe and later worked with the Morkrum Company (now Teletype) which he represented in Europe from 1919 to 1922. In 1924, Mr. Wishart returned to Postal as Printer and Automatics Engineer, and subsequently held the positions of Central Office Engineer, Inside Plant Engineer and Chief Engineer. Since the merger of Postal and Western Union in 1943 Mr. Wishart has contributed much to the development and expansion of reperforator switching systems. He is a member of AIEE.

so many short communication sections. Perhaps at a later date the demand for direct communications between points far enough apart will grow into a bundle large enough to justify the capital expenditures involved in applying such multiplexes. There have been many other ideas for applying synchronous methods to a system such as Western Union's. They include feeding a controlling frequency throughout the country so that all offices would have identical fork frequencies to drive distributors. In part, this was done years ago by utilizing a master control for all sending distributors in an office but this does not allow for a variety of speeds. Another suggestion has been to synchronize the universe by having one transmission fixed and governing all transmitters in the system by pulsing them from the reception at each station. The transition of received signals would create the pulse. Such a train of impulses would not be compatible with way wire operation of several types.

The inflexibility and cost of multiplex works against it when Western Union is endeavoring to meet the business public's desires for varied types of transmissions over moderate distances, comprehending everything from various teleprinter speeds and telemetering, through facsimile to high-speed data.

The author feels that the Empire of Multiplex as we know it has come to an end in Western Union except for certain special uses, cable operation being one of them, where the need for obtaining channels without filter spacing losses is transcendent.

Certainly, synchronous methods will be used in many high-speed data systems to obtain the utmost out of the slices of the frequency spectrum. Because of delay distortion encountered in wideband circuits, such high-speed systems will require rather frequent regeneration and the synchronous method simplifies the regenerators and also circuit testing. It is further felt that the stability resulting from synchronous operation will be desirable at the high speeds. Application of the encryption systems of the military services is usually simplified by synchronous operation.

The answer to the question at the beginning of the article appears to be that for many years start-stop operation will continue to grow in use on land lines and the use of the ordinary multiplex diminish. High-speed data systems for stability will require synchronous methods, high capacity multiplexes of novel designs will be applied to cable and to radio where distances are great enough to absorb the costs. They may reappear on land lines in the new form when demand between two distant points becomes sufficient.

References

1. SMALL TERMINAL OFFICE REPERFORATOR, RONALD S. WISHART and GEORGE STRANZ, JR, *Western Union Technical Review*, Vol. 10, No. 2, April 1956

   SOME RECENT WESTERN UNION DEVELOPMENTS IN PRINTING TELEGRAPH APPARATUS, FRED W. SMITH, *Western Union Technical Review*, Vol. 12, No. 3, July 1958.

3. AUTOMATIC TRUNK SELECTION IN REPERFORATOR SWITCHING, W. B. BLANTON *Western Union Technical Review*, Vol. 6, No. 1 January 1952

4. FCC Docket No. 11646 Exhibit No. 2bs interstate Circuit Data as of March 31 1956, Binder No. 2, The W...

   PLAN...... SUMMARY OF CABLES, H. F. WILDER, *Western Union Technical Review*, Vol. 11 No. 1, January 1957

C. H. DALRYMPLE entered Western Union service in 1933 as a messenger boy at Texarkana, Ark., and subsequently served in clerical, operating and T&R capacities at various points in the south and southwest; for a number of years he was an Assistant Automatic Chief in New York City and New Orleans. He has been active in the testing of switching centers starting with Plan 21 and going on to Plan 51 in the theory of which he also instructed Air Force technicians. Mr Dalrymple later instructed in the theory of Plan 54 and participated in the testing of the first of those centers. As General Maintenance Supervisor he was technical adviser for Canadian National Telegraphs during installation and testing of their first Plan 54 center. As the accompanying article indicates, he was closely associated with maintenance in the Plan 55 program and assisted in development of training courses for Western Union and Air Force personnel, in testing the system at Chattanooga and Andrews AFB, and in coordinating the testing of the five domestic switching centers.
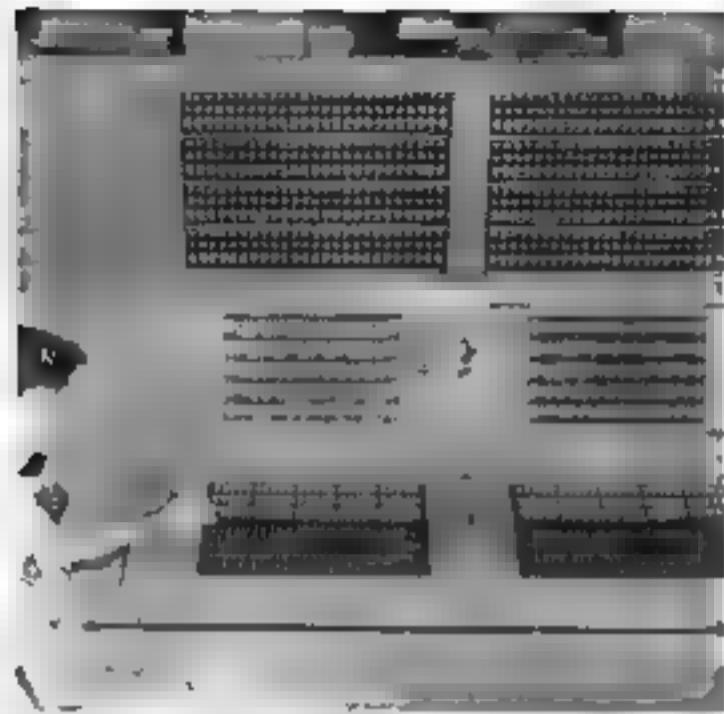
Traffic Control Supervisor's Cabinet with close-out indicators, traffic patching jacks and connection indicators
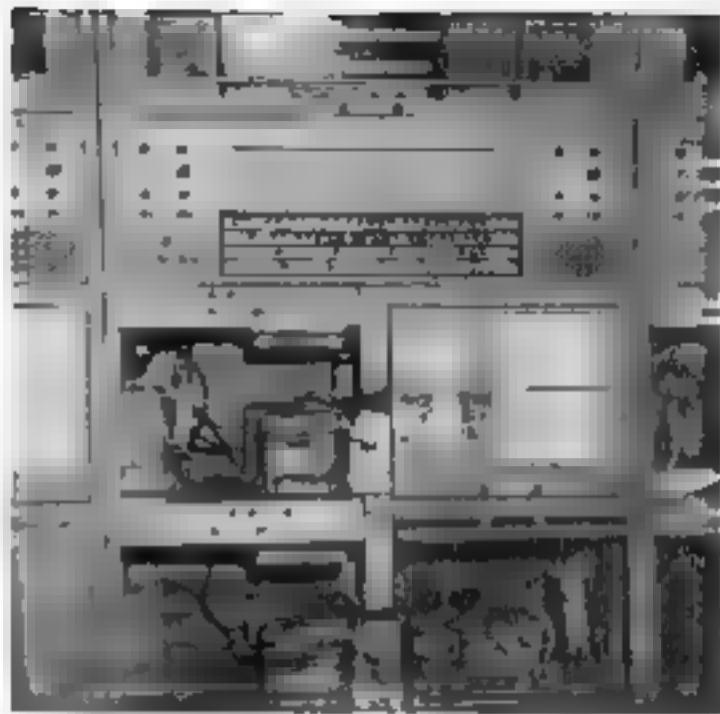
Receiving Cabinets 7502-A, showing loop-gate tape transmitter and printer-perforator

C. H. DALRYMPLE, Area Plant Superintendent, New Orleans, La.

Maintenance of USAF Plan 55 Switching System

Designed for the United States Air Force by Western Union engineers, a high-capacity automatic telegraph switching system has been in domestic military service since 1958. The network now is being extended to serve U. S. air bases overseas. A well organized and efficient maintenance program is carried on by military personnel under Western Union supervision.

THEORY, operation, and equipment design innovations of Switching System 55-A, familiarly called Plan 55, have been described in previous issues of Technical Review.[1,2] This fully-automatic high-speed switching system was designed to satisfy the specific requirements of Airways and Air Communications Service, the communications group of the United States Air Force, and to accommodate the special message format used throughout its global network.

U. S. A. Network

On November 22, 1958 the last of five Plan 55 switching systems in the USAF domestic network was placed in service, and an important milestone in communications was quickly passed. As each of these switching centers was cut over into the Air Force communications system, maintenance procedures and records were simultaneously placed in effect to assure continued smooth operation of the complex electromechanical equipment. Dates of the cutovers were.

Andrews AFB, Washington, D. C	March 29, 1958
McClellan AFB, Sacramento, Calif	May 31, 1958
Wright-Patterson AFB, Dayton, Ohio.	August 2, 1958
Carswell AFB, Ft. Worth, Texas.	October 4, 1958
Warner Robins AFB, Macon, Ga. .	November 22, 1958

Airman using Relay Test Set 6502.1-A to adjust rotary switches on Rotary Switch Chassis 7575-A
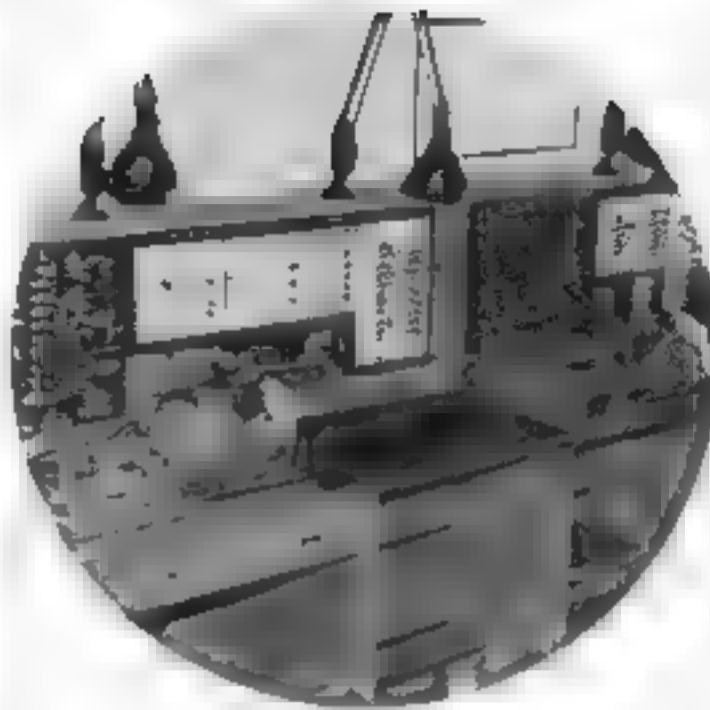
Electronic Test Table 9414-A and Electronic Test Table 9412-A specially designed for Plan 55 maintenance

Perhaps a brief flash back into the history of Plan 55 engineering development will help to dispel any notion that maintenance of the system might be drab, uninteresting, or even entirely routine in nature.

First, as the October 1956 article pointed out, cabinets and movable equipment had to be designed so that all components were accessible for observation or adjustment. The concept of "swap-out" maintenance was expanded so that a relay chassis, readily replaceable as a unit, incorporated all resistors, capacitors, and immediate control circuitry associated with the 30 to 40 relays mounted upon its frame. Possibility of long outages is thus considerably reduced. Anticipated maintenance needs were considered in design of such units as electronic chassis, and all vacuum tube elements and test points were extended to test jacks mounted on the face of each chassis, so that test leads from meters or oscilloscopes might be inserted.

It was immediately apparent that periodic testing of vacuum tubes on a tube tester would be impractical. First, some trouble would be introduced by frequent removal and replacing of tubes. The most important factor, however, is the large number of tubes present in an average-size switching center. In such a center there are by actual count 15,500 vacuum tubes, consisting of 31 different types. "Technical Control" installations for testing and regulating add 300 more to the total.

Special test tables had to be designed to simulate most of the normal operating functions. Most of the control circuits connecting purely mechanical apparatus to electronic units are so interrelated that they cannot be separated, but must be tested as complete entities. Since this entirely new switching system combined electronic pulse techniques (employed on a wide scale for the first time in Western Union) with mechanical units also in use for the first time—loop-gate transmitter[2] and Teletype Model 28 LBXD (distributor-transmitter), LARP (reperforator), and LPR (printer-perforator)—troubleshooting techniques were devised to diagnose each new case of trouble as it developed. Additions or changes to test equipment were then made as required.

The history of maintenance may be divided into three periods:

Prototype system at Chattanooga
April 2—July 27, 1956

Prototype system at Andrews AFB,
August 1, 1956—February 1, 1958

Operation in Z/I (domestic) network,
starting March 29, 1958
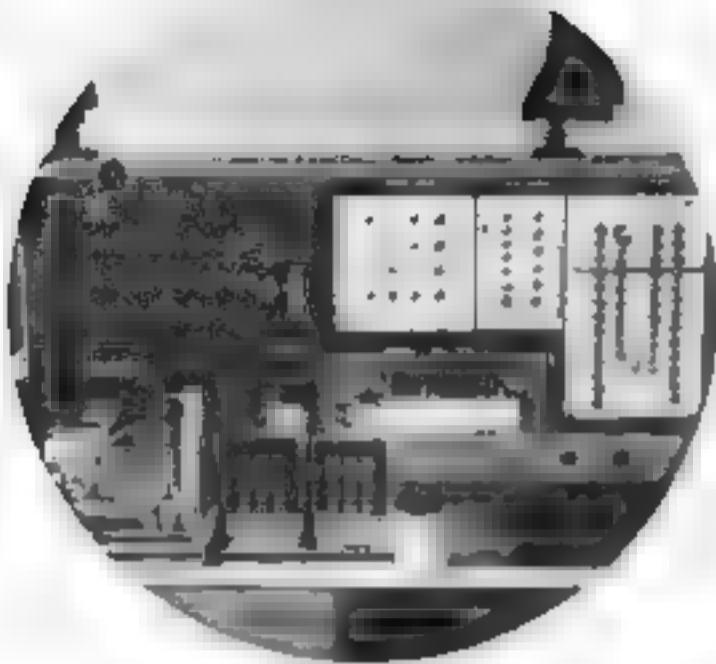
Cross-Office Test Table 7454-B includes electronic trans-
mitter, pulse generator and receiver panels
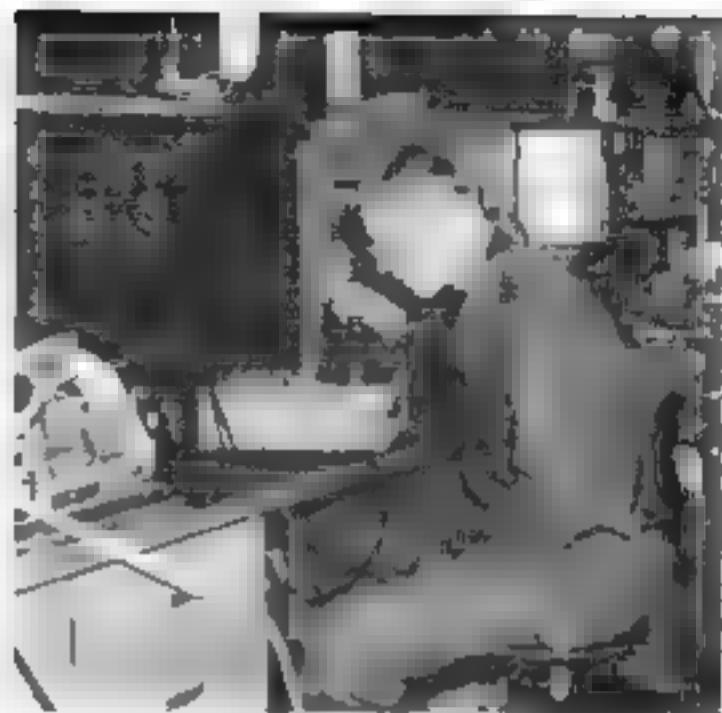
Airman adjusting 203-A Relay on Portable Relay Test
Set 5605-A in accordance with Western Union specifica-
tions

The first two phases were important in
the development of necessary improve-
ments and in devising trouble-shooting
methods, and actually constituted an ex-
tension of the engineering tests begun in
the laboratories at New York

Operating Trials

Engineering and maintenance person-
nel, together with trained Air Force tech-
nicians, operated the Chattanooga proto-
type installation under simulated traffic
conditions. Some circuit revisions were
made as a result of these tests, and Tele-
type and Western Union personnel ap-
plied mechanical changes indicated by the
Chattanooga trial

As the tests proceeded, many small
problems, unrelated to design changes
made to improve performance, were en-
countered and had to be solved. New and
special tools were found necessary to
make certain adjustments or to reach re-
mote test points. A list of all necessary
hand tools (over 150) was compiled, so
that sets of proper tools could be provided
for all maintainers coincident with instal-
lation. In order to maintain even an
engineering prototype, an adequate sup-
ply of piece parts had to be supplied to
replace worn or broken parts. First, esti-
mates were made of parts judged suscep-

tible to wear, breakage, or electrical
failure. Later, complete lists of hundreds
of individual parts in each of the many
mechanical and electronic elements com-
prising the system were prepared, and
parts were placed in reserve stock accord-
ing to usage experienced during phases
one and two

On August 1, 1956 the entire prototype
installation was moved to Andrews AFB
near Washington, D. C., and installed in
the communications center. From October
13, 1956 until February 1, 1958 operation
of the equipment was observed while a
light load of actual Air Force message
traffic was being processed, and additional
Air Force maintenance personnel were
trained. Maintenance procedures were de-
veloped during this period, and record
forms were formulated so that apparatus
failures could be quickly summarized by
types, causes, and so forth. Use of these
forms was of considerable value in making
further necessary changes in equipment.

During this phase, while additional
Western Union and Air Force personnel
were receiving training in theory, opera-
tion, maintenance, and testing of the
equipment, a complete 15-week training
course was developed. Beginning Septem-
ber 4, 1956 a series of classes based on this
course was conducted at Chattanooga
for a total of 154 airmen. During the over-

laps of classes there were as many as 16 instructors assigned. Graduation of classes was scheduled to coincide with installation of switching centers.

When the third phase of Plan 55 maintenance (actual operation of centers) began, the methods and records which were initiated during the test phases were placed in effect.

Maintenance Organization

An entirely new concept of maintenance responsibility, both for Western Union and for the Air Force, began when the Andrews AFB center was cut over In accordance with the domestic maintenance contract, a joint responsibility was established: Western Union supervisory personnel (six per center, including a "center chief") are assigned to provide continuous coverage. Trained Air Force maintenance personnel are assigned to each center on shifts. A "flight leader" is assigned to each shift to handle administrative supervision and to work with the Western Union supervisors in making assignments for each tour. All flight leaders report to a noncommissioned officer in charge (NCOIC), who is subordinate to a Maintenance Officer (usually a Warrant Officer or Captain). A Project Supervisor is assigned responsibility for the local force of Western Union supervisors. All procedures, policies, and other joint enterprises are decided upon cooperatively by the Western Union Project Supervisor and the Air Force Maintenance Officer. Maintenance methods and routines are controlled by Western Union personnel; direct supervision of Air Force maintainers is effected through military organizational channels.

Essential local records are maintained so that performance can be evaluated, failures analyzed, and parts usage controlled. A form, originally pocket-size, is used to describe every case of trouble, showing time, cause, and remedy. These entries are transcribed into a logbook at the end of each tour, and studies are made periodically of all interruptions. Forms are exchanged between Air Force Technical Controls (testing and regulating)

and Plan 55 operating centers, so that all land-line or radio circuit failures may be recorded. Standard card records are maintained to show apparatus failures. A special form is used to show cause of equipment trouble and repairs made, and another is used for the life history of an individual unit. Information derived from these records is compiled weekly and submitted to the General Office for analysis. These routines are modified, of course, as experience dictates.

Technical control test bays

As improved methods of maintaining equipment or analyzing failures are developed, bulletins are issued to all personnel. These are numbered sequentially, so that each man may maintain a complete file of all information and instructions. Dissemination of these bulletins on an individualized basis, combined with a program of formal "review" instruction at each center, is calculated to maintain a high degree of interest in the maintenance of a center by every man assigned there

References

1. DESIGN TRENDS AND CONCEPTS AS APPLIED TO PRIVATE WIRE TELEGRAPH ENGINEERING, WARREN H FISHER Western Union Technical Review. Vol 10 No. 4. October 1956

2. AUTOMATIC TELEGRAPH SWITCHING SYSTEM PLAN 55-A G. BERT S. VERNAM, Western Union Technical Review Vol. 12, No. 2, April 1938

3. MAINTENANCE AND OPERATIONS TRAINING CENTER, Chattanooga, Tennessee. G. E. HOFFSTETTER, Western Union Technical Review. Vol. 13. No. 4, October 1959

HAROLD F. WILDER IS 1959 D'HUMY MEDALIST

•

HAROLD F WILDER was presented with the 1959 F. E. d'Humy Award by Western Union President Walter P Marshall at formal ceremonies on September 30 in New York. Mr. Wilder is assistant to the electronics applications engineer, Research and Engineering Department, at company headquarters. In addition, former medalists present were given gold lapel buttons symbolic of their awards of previous years.

Guest speaker at the presentation was Dana W. Atchley, Jr., president of Microwave Associates, Inc., a research and development organization affiliated with the Telegraph Company, who was introduced by H. P Corwith, vice president in charge of research and engineering for Western Union. In his talk entitled "Intelligence Exchange in the Space Age," Mr. Atchley referred to interesting aspects of his recent visit with Russian electronics experts in Moscow and Leningrad. The other principal speaker was Ray Hoover, the Telegraph Company's vice president in charge of plant, whose subject was "Western Union's Blueprint for Communications Progress."

Mr Wilder is the fifth recipient of this honor which has been awarded annually since 1956 to a Western Union engineering, research or technical worker who has made a most significant contribution to the telegraph art. The Award includes a French bronze medallion, an engrossed citation certificate, a gold pin or lapel emblem and a $500 honorarium. It was established by The Western Union Telegraph Company in commemoration of the leadership in telegraph research and engineering brought to the company by Fernand E. d'Humy, former vice president and a director, who died December 22, 1955

The citation to Mr. Wilder, which reads "For innovations promoting the art of landline and submarine cable telegraph transmission and signal regeneration," takes particular cognizance of his work on ocean cable circuitry, including among many outstanding accomplishments the multiplexing and extension of submarine telegraph channels, electronic signal regeneration, inventions in bias measurement methods and equipment, and development of other instrumentation devices. He is credited with conceiving the original idea for applying submerged repeater amplifiers to Western Union's transatlantic cables, an arrangement which has increased their message capacity manyfold. He is the author of technical papers including "A Self-Regulating Multiplex" which appears in this issue of TECHNICAL REVIEW

A graduate of Northeastern University, Mr. Wilder joined the Engineering Department of Western Union in 1929. He is a member of the American Institute of Electrical Engineers.

EDGAR S. GRIMES, Senior Project Engineer, Transmission

Vestigial Sideband Transmission as Proposed for Intercity Facsimile Signals

It has long been known that either of the two sidebands created by the amplitude modulation of a carrier contains the same information, hence if one sideband can be eliminated less bandwidth is required for the transmission of intelligence. Intercity facsimile communication systems take advantage of this fact, but owing to practical design limitations a portion of the unwanted sideband remains, hence the designation vestigial sideband transmission.

THE VESTIGIAL sideband carrier current method of transmission has been applied to many types of signals, such as television, facsimile and business data. The fact that facsimile signals are sent over voicebands, that vestigial facsimile signals require less bandwidth than double sideband signals, and that the vestigial method produces signal distortion known as the quadrature component is familiar to most communications people. Not so familiar, however, are the techniques for modifying the signal vector group by network components, thereby overcoming at the sending and receiving terminals the limitations of an intercity voiceband circuit as a transmission medium for vestigial facsimile signals.

Several variations of the vestigial method of transmitting facsimile signals are in daily operation at reduced speeds and with some quadrature distortion. This paper presents a type of vestigial sideband correction circuit being currently developed that operates at near maximum speed and with low distortion at 100-percent modulation. The voiceband has an approximate amplitude versus frequency range from 300-3300 cycles thereby restricting the carrier frequency to the neighborhood of 2900 cycles and the signal speed to a maximum around 2400 cycles when the circuit delay distortion is corrected. This paper gives a general description of the steps or stages required to modify the signal vectors at the transmitting terminal before the signals are sent over a voiceband, and the stages required at the receiving terminal to restore the signal vectors before applying the signal

wave to the recording stylus. By the proper processing of the signal vector group it is possible to obtain maximum speed (2400 cycles) with minimum over-all distortion from an intercity circuit, since all signal envelope shapes from phototube to stylus are directly related to the characteristics of the group of vectors under the envelope. There are seven possible causes of distortion to the received signal envelope but they are controllable by the design of the receiving terminal equipment with the exception of bandwidth and noise.

The vector group characteristics are similar to the characteristics of an individual vector such as the amplitude of voltage or current, the frequency and the phase. In a group of vectors the envelope of the group may be modified by (1) adding a vector to the group or subtracting a vector from the group; (2) changing the relative amplitude of the vectors to each other; (3) altering the frequency ratio of the vectors to each other; (4) changing the relative phase of the vectors to each other. These four characteristic factors of the vector group are modified and controlled by the normal terminal circuit components, such as modulators, filters, detectors and equalizers. The graphic relationship between the vector group in the frequency domain and the carrier current envelope in the time domain is shown on Figure 1 for the principal signal forms at different over-all circuit locations such as

(a) *Phototube Output Wave.* The generation of a negative signal by a scanning aperture and a phototube.

(b) *Double Sideband Wave at Sending Terminal.* The generation of a double sideband envelope on a carrier several times higher in frequency than the signal.

(c) *Vestigial Sideband Waves on Voiceband Circuit.* The transfer of the envelope to a carrier only slightly higher in frequency than the signal and the elimination of one sideband.

(d) *Second Vestigial Wave at Receiving Terminal.* The transfer of the envelope back to a high-frequency carrier with the envelope inverted and the quadrature component neutralized.

(e) *Recording Stylus Wave.* The detected high-frequency envelope giving a positive signal wave required for recording

The direct signal waves (a) and (e) are the instantaneous sum of the vector group with time but the envelope waves (b), (c) and (d) are the locus of the peaks of the modulated carrier cycles and represent an idealized signal wave. The phototube output wave is the negative of the copy scanned and generates three vectors as shown,—a fundamental frequency f_1, a second harmonic $2f_1$, and a dc component. Vectors f_1 and $2f_1$ rotate counterclockwise and the indicated relative positions of the vectors to each other occur at approximately the instant of time a on the waveshape. At circuit location (b) a 10,000-cycle carrier C has been modulated by f_1 resulting in a carrier envelope having an upper sideband vector U, and a lower sideband vector L.

This whole vector group C, L and U is rotating counterclockwise but the rotation of the vectors relative to each other is as shown; U is rotating counterclockwise relative to C but L is rotating clockwise relative to C. The vector $2f_1$ contained in the phototube signal has been eliminated by a filter and the dc vector has been replaced by a carrier vector C. At position (c) only two vectors are present, C and L. Here the low-frequency 2900-cycle carrier voiceband vestigial wave has developed two envelope distortion factors, (1) a quadrature component due to suppressing
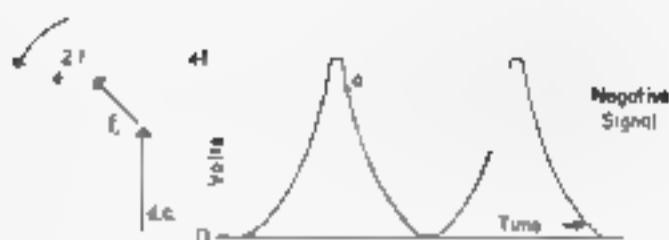
(a) Photo Tube Output Wave
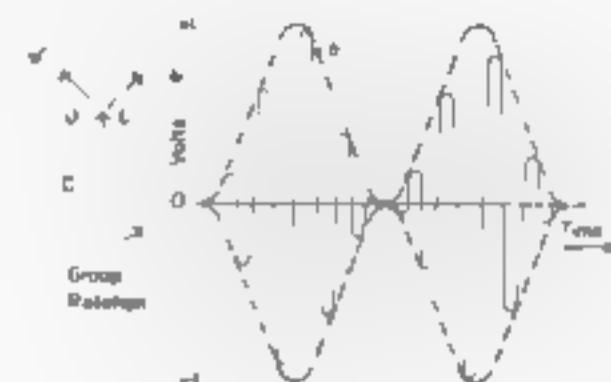
(b) Double Side Band Wave

(c) Voice Band Vestigial Wave
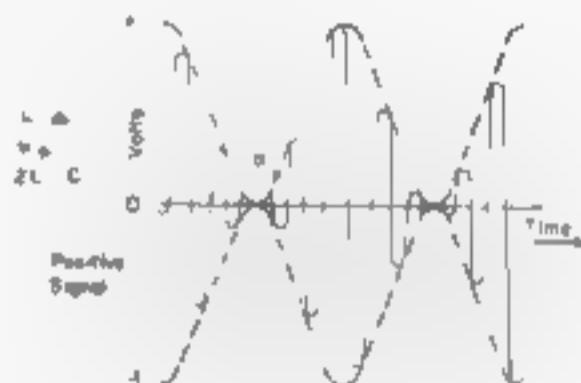
(d) Receiving Terminal 2nd Vestigial Wave

(e) Recording Stylus Wave

Figure 1. Relation between signal waveshapes and their vector components

(a) Double Side Band Vectors

(b) Vestigial Network Characteristics

(c) Detected Envelope Characteristics
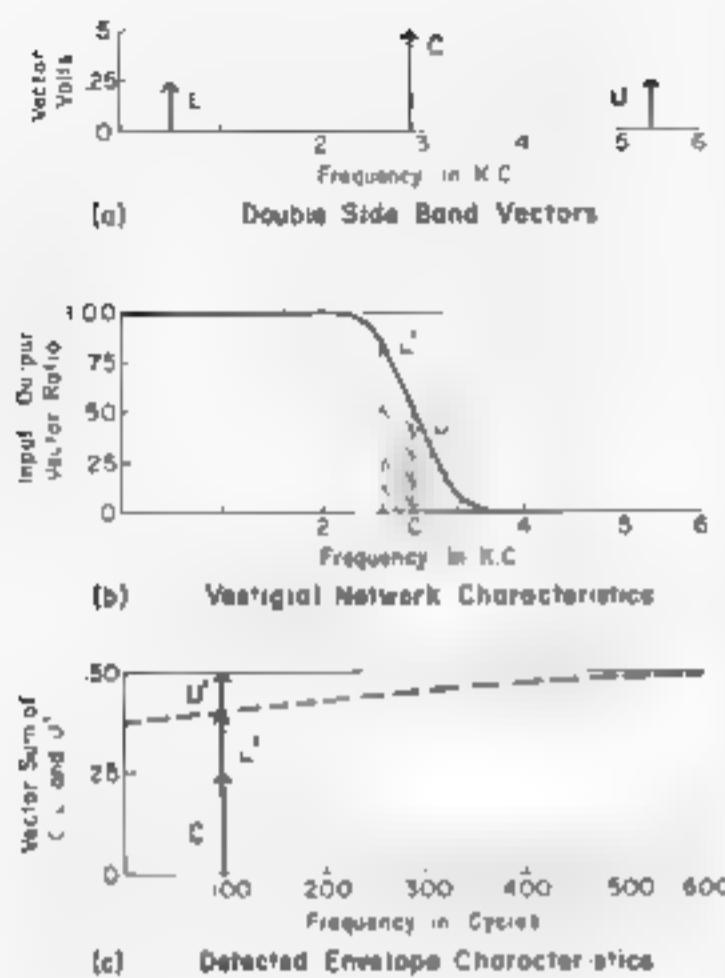
Figure 2. Generation of vestigial signal

(a) Vestigial Envelope

(b) Detected Vestigial Envelope

(c) Detected Envelope Frequency Components

Figure 3. Frequency components of vestigial envelope before and after detection

the upper sideband U with a filter, and (2) an amplitude pattern in the carrier due to the low ratio of carrier frequency to signal frequency. At the receiving terminal the wave at position (d) has been obtained by transferring the envelope at position (c) from the 2900-cycle carrier to a 10,000-cycle carrier, then detecting that envelope, inverting the wave and remodulating a second high-frequency vestigial envelope. By doing this the relative length of C to L is modified, a second order lower sideband $2L$ has been created, and a small third order lower sideband $3L$, not shown, is also created These changes in the vector group have operated to predistort the double sideband envelope, making it possible to neutralize the influence of the quadrature component introduced in the second vestigial process. At position (e) is shown the detected envelope of the second vestigial wave which indicates low bias distortion and low harmonic distortion

Generation of Vestigial Sideband Carrier Current Envelope

A vestigial sideband carrier envelope is derived from a double sideband carrier in a direct manner by attenuating all but a vestige of one sideband with a filter having a specially designed attenuation region. A well-designed vestigial filter network reduces the carrier vector to 50 percent. and has an attenuation characteristic in the neighborhood of the carrier such that the detected envelope will have a constant amplitude as the modulation frequency is varied from a few cycles to 2400 cycles.

The relative magnitude and the frequency of the double sideband vectors under the envelope of a 2900-cycle modulated carrier are shown in Figure 2(a) for a 2400-cycle signal. The sum of the vector group at their maximum amplitude is one unit. The carrier C is 0.5 units long the lower sideband L is 0.25 units long. and the upper sideband U is 0.25 units long By passing these vectors or frequencies through a vestigial network having the output-to-input characteristic of Figure 2(b) the vector group is modified in number and relative magnitude. Vector L
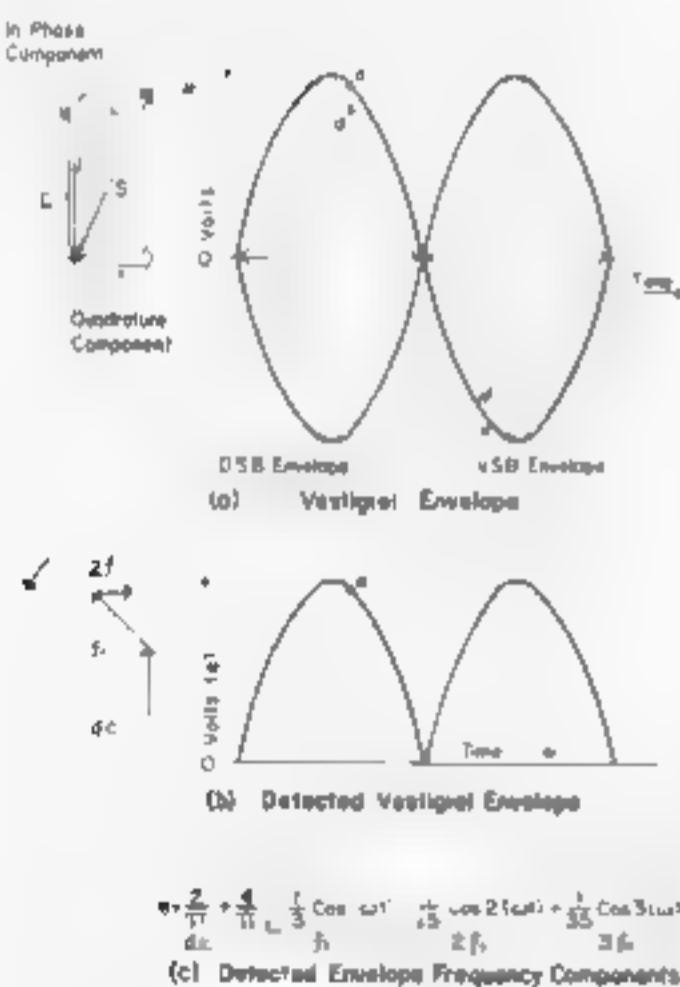
is unchanged, vector C is reduced 50 percent and vector U is completely suppressed. A test of the correct design of the output-to-input characteristic in the neighborhood of the carrier, such as the shaded area L' and U', is the frequency-amplitude characteristic of the detected output envelope.

The quadrature component distortion is an inherent part of a vestigial envelope and is the envelope obtained by the addition of any two sine waves of different frequency over a period of time equal to the period of the beat frequency between them. Mathematically the vector representing the quadrature component of dis-

(a) Transmitting Terminal

(b) Receiving Terminal—1st Section

(c) Receiving Terminal—2nd Section
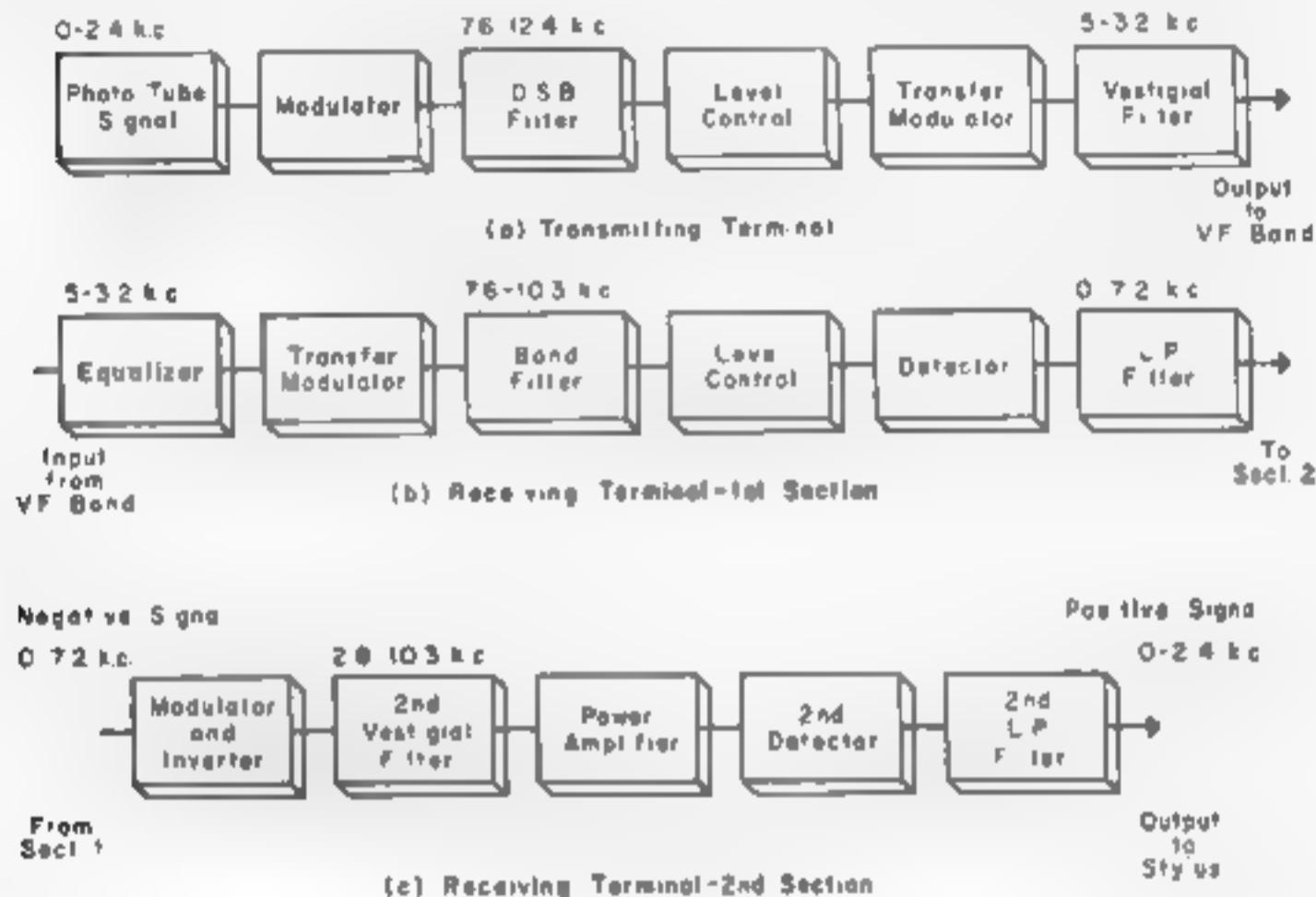
Figure 4. Block diagram of terminal components

Figure 2(c) shows that as the carrier modulation is varied from some low frequency such as 10 cycles, comprising essentially a double sideband system, to 300 cycles and beyond to 2400 cycles, the maximum sum of the vector group remains constant at 0.5 units. In Figure 2(c) the sum of 0.5 units is maintained while L' and U' vary in a complementary manner over the first 300 cycles to a constant L' above 300 cycles to 2400 cycles. However, although a constant amplitude has been obtained at all frequencies, the suppression of the upper sideband has modified the shape of the carrier envelope from a sine wave, introducing the type of distortion known as the quadrature component previously noted in Figure 1(c).

tortion is determined by resolving vector S into two stationary vectors at right angles to each other, giving the quadrature component and the in-phase component as shown on Figure 3(a). The in-phase vector is in phase with the carrier C and changes its magnitude relative to C but does not rotate relative to C. The quadrature component vector is at right angles to C and changes its magnitude relative to C but does not rotate relative to C. The magnitude of the vectors shown is approximately as at instant of time a on the solid line vestigial sideband envelope. The dotted line envelope is the shape of the original double sideband envelope and the difference between the two is attributable to the quadrature

component. The detected vestigal envelope is shown on Figure 3(b) and its vector group is related to the carrier vector group by the relationship that f_1 is equal to the difference in frequency between C and L, and the carrier vector C has been replaced by vector dc. The equation at Figure 3(c) indicates that the detected envelope has introduced second and third harmonics and d-c bias distortion into the signal. The magnitude of these harmonics and the d-c bias distortion, as measured by the departure in length of the dc vector from 0.5 volts, can be greatly reduced in two ways: (1) by reducing the percent modulation to 50 percent, and (2) by inverting, remodulating and transmitting through second vestigial network at the receiving terminal. Method (2) is discussed later

Block Diagram

If the facsimile signals were not required to be transmitted over substantial distances, the minimum electronic and network components necessary for making facsimile copy would reduce to a phototube excited from a scanning aperture with a light chopper, and an amplifier possessing adequate power to cause the recording stylus to mark on "Teledeltos"[*] paper. However, the transmission of these same facsimile signals over an intercity voiceband at near maximum signal speed, 2400 cycles, requires 17 electronic and network components for maximum performance. Figure 4 is the block diagram of the electronic and network components at the transmitting and receiving terminals that are necessary to condition the signal vector group before and after transmission over an intercity voiceband. The transmitting terminal delivers to the voiceband a vestigial envelope signal that is level regulated, free of signal harmonics above 2400 cycles, free of the unbalanced signal energy that would lie within the voiceband range, and free of second and third order sidebands. At the transmitting terminal the voiceband vestigial envelope on 2900-cycle carrier is obtained indirectly from the photo-

[*] Registered Trademark, W. U. Tel. Co.

tube signal generator by way of a double sideband signal on a 10,000-cycle carrier, as shown in Figure 4(a). The phototube generates signals in the band from zero to 2400 cycles and this signal modulates a 10,000-cycle carrier placing the signal band at 7.6-12.4 kc. (See Figure 1(b))

The double sideband filter for this band

(a) Inverted Detected Wave

(b) Double Side Band Wave Generator By Inverted Detected Wave

(c) 2nd Vestigial Side Band Wave

(d) Detected Envelope of 2nd Vestigial Side Band Wave
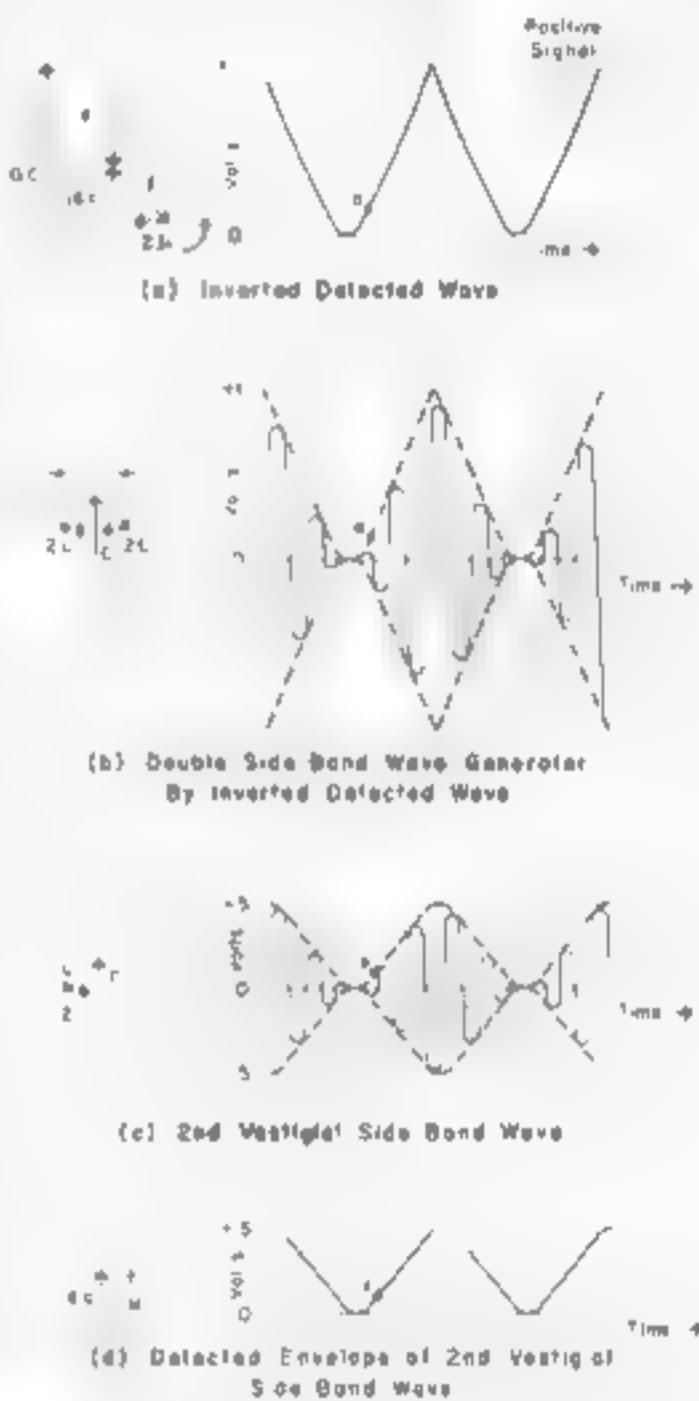
Figure 3. Quadrature component correction by second vestigial process

eliminates unwanted signal harmonics and unwanted modulation products that are not possible to eliminate by direct modulation on 2900-cycle carrier. Variations in signal level are stabilized by the level control and to some extent the percent modulation is also stabilized. The 10,000 cycle signal envelope, the locus of the

peaks of the modulated carrier, is transferred to the 2900-cycle carrier by the transfer modulation and the vestigial filter eliminates the upper sideband before transmitting the facsimile signal to the voiceband. (See Figure 1(c)) The sending terminal output signal is the negative of the copy scanned since the white areas produce maximum power output. Transmission over the line adds further distortion to the vector group by modifying their amplitude and phase.

In the first section of the receiving terminal, Figure 4(b), four of the factors causing distortion in the received wave envelope are removed. The voiceband circuit equalizer corrects the amplitude and phase distortion introduced by the intercity transmission channel and produces a replica of Figure 1(c) at its output. The frequency ratio between the carrier and the signal is increased from 1.2 to 4.15 with the transfer modulator that transfers the envelope from a 2900-cycle carrier to a 10,000-cycle carrier. This process removes the amplitude distortion pattern present in the envelope to give the familiar waveshape of Figure 3(a), solid line. The circuit level corrector stabilizes attenuation variations. The output of the first section of the receiving terminal has the waveshape shown in Figure 3(b) with the harmonic distortion and d-c bias distortion that is introduced indirectly by the quadrature component in the vestigial envelope.

Quadrature Component Neutralized

The process by which the signal distortion of Figure 3(b) is neutralized in the receiving terminal second section, Figure 4(c), is illustrated in the waveshapes

and vector groups of Figures 5(a) to 5(d). The first step is to invert the detected wave and add an opposite sign direct-current vector D.C. to the vector group. The resulting vector group shown in Figure 5(a) is the new dc vector shown dotted, the signal vector f_1 and the second
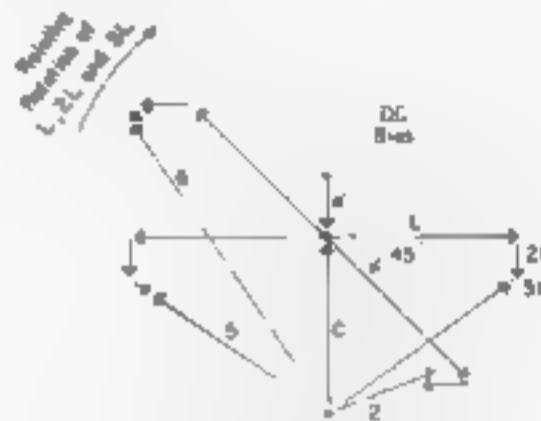
(a)   Vector Diagram
of C with D C Bias and Inverted
L, 2L and 3L
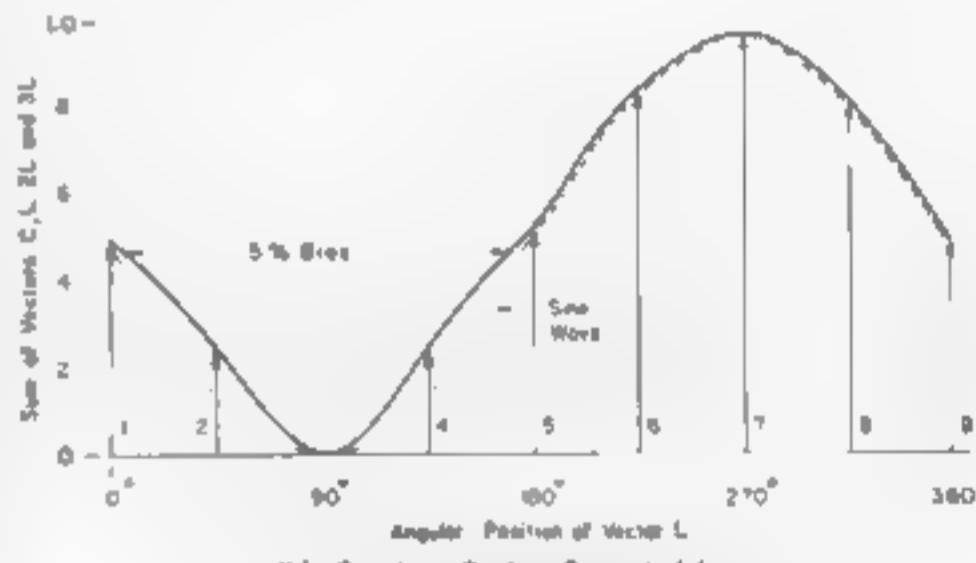
(b)   Envelope Contour Generated by
Carrier and Inverted
Lower Side Band with Harmonics

Figure 6.   Single sideband envelope contour from predistorted signal

harmonic vector $2f_1$. The resulting waveshape of Figure 5(a) is applied to a second vestigial modulator and network circuit at the second section of the receiving terminal, shown in Figure 4(c), where it is remodulated on a 10,000-cycle carrier to produce the double sideband vector diagram and distorted carrier envelope shown in Figure 5(b).

This predistorted envelope will now neutralize the envelope distortion created by the quadrature component vector in

the second vestigial filter. The resulting vestigial envelope and vector group are shown on Figure 5(c). This carrier envelope has the appearance of a double sideband shape but in its vector diagram the upper sideband U has been replaced by higher order sidebands $2L$ shown, and $3L$ not shown, and a shortened carrier vector C. Detection of this envelope gives the low distortion positive signal wave of Figure 5(d) with its vector group comprising vector f_1 and vector dc only. The output of the second section of the receiving terminal is applied to the recording stylus and is an inverted replica of the phototube signal of Figure 1(a), minus aperture distortion.

This paper has shown that similar envelope contours can be obtained from entirely different vector groups such as the double sideband envelope of Figure 1(b) and the vestigial sideband envelope of Figure 5(c). The envelope of Figure 5(c) contains four vectors, three vectors shown and one vector $3L$ not shown, and thus

envelope is an inverted replica of Figure 1(b) which contains only three vectors. The vector diagram of Figure 5(c) is shown in detail in Figure 6(a) and illustrates how the instantaneous sum of all the vectors neutralizes the influence of a single quadrature component vector. The sum vectors 1, 2, and so forth, are shown in Figure 6(b) from 1 to 9 for various angular positions of vector L. The sum vectors are the instantaneous sum of the biased carrier vector C and the inverted vectors L, $2L$ and $3L$ at various angular positions of L giving the relatively distortion-free envelope contour of Figure 6(b). Since the vector C, shown stationary, is in fact rotating counterclockwise, the sum vectors 1 to 9 develop either positive or negative lobes and an oscilloscope display would look like Figure 5(c). The end result of reducing the vestigial envelope distortion is greater visual resolution in the facsimile copy for a given transmission bandwidth and 100-percent modulation.

EDGAR S. GRIMES joined the Transmission Division of Western Union in 1928 shortly after graduating from Northeastern University with a B.E.E. degree. His early assignments included work on carrier equipment and the design of wideband multichannel amplifiers and modulators. Thousands of these components are in daily use in the various Western Union carrier systems, including over 2000 of one type of amplifier. His knowledge of carrier systems was applied to facsimile transmission and his research studies resulted in the practical design of intercity vestigial sideband circuits operating at speeds from 180 rpm to 1200 rpm, the mitigation of impulse noise, and the d-c transmission of 4800-bit facsimile signals over customers' loops. He holds patents on a low-distortion multichannel modulator and a device for suppressing white noise interference in facsimile recordings, and a patent is being applied for on a circuit that neutralizes the quadrature component in a vestigial system. Mr. Grimes is a registered Professional Engineer in the State of New York.
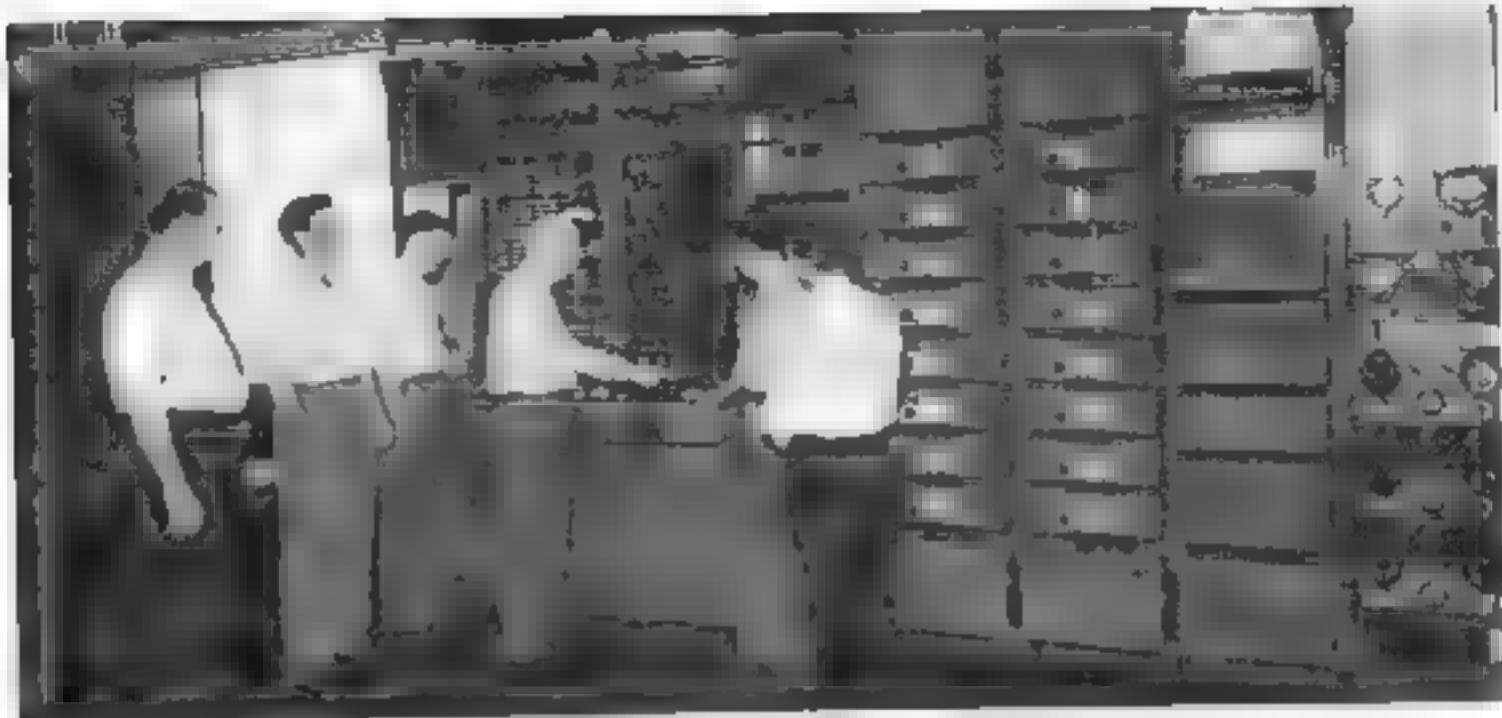
Staff examines one of training center's carrier telegraph terminals prior to start of classes in 1953 From left, Messrs Mills, Walker, Shofer Tater, Hanes and Reckard discuss proposed equipment instruction program

G. E. HOFFSTETTER, General Operations Supervisor

Maintenance and Operations Training Center Chattanooga, Tennessee

In addition to regularly scheduled short courses in telegraph equipment maintenance and circuit operations procedures, a Training Center can provide special programs and seminars which help keep personnel well informed on continuing technical advances as they influence telegraph practices.

PRIOR to extensive mechanization of the telegraph industry, on-the-job training of Western Union maintainers and technicians fulfilled most requirements. With the advent of reperforation, customors' switching systems, FM carriers and other electronic equipment, the need for a planned training program became apparent

Early in 1953 several General Office and Area supervisors met at Chattanooga to discuss such matters as a location for a maintenance and operations training center, and the subjects to be taught. Inasmuch as a suitable building was available on the grounds of the company's Chattanooga Works,[2] and hotel accommodations were adequate, Chattanooga was chosen as the site

Apparatus Installed

The building was divided into two large laboratory rooms, one for maintenance and the other for operations. The maintenance area was equipped with various types of selectors and other equipment found outside of main offices, and a lecture room was partitioned off from the maintenance laboratory. The operations laboratory was equipped with duplicate equipment representing two wire and repeater rooms. This room was also used for lectures

The original plan provided for the training to be done by an operations supervisor and a maintenance supervisor from the General Office, assisted by Area supervisors to be detailed for a few weeks at a time. Under such an arrangement, the

Lecture on circuit analysis is given with aid of instrument-and-diagram panel board plus test set demonstrations
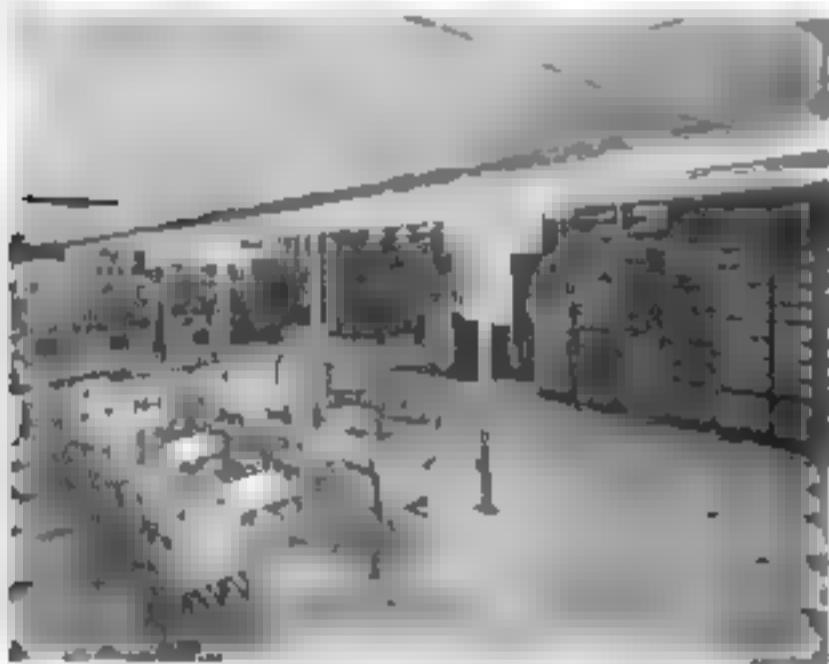
Circuit operations laboratory and lecture room of Western Union's Maintenance and Operations Training Center

Student group, assisted by instructors, checks knowledge of circuit diagrams in written quiz at Chattanooga school

Areas would have an active part in the training program. Initially, the maintenance training period was five weeks and operations two weeks. These periods were later changed to the basic ten-day sessions now in effect. No classes were scheduled during the months of June, July and August

Classes started in the fall of 1953. Maintenance Instructors conducted classes in basic electricity, Telefax, single and duplex way-station selectors. Operations instructors conducted classes for apprentice wire and repeater technicians and several special meetings were held on both sides. The size and number of classes together with other demands on the training facilities grew until the two large rooms became inadequate

In January 1957 construction of four additional air-conditioned and electrically heated lecture rooms was begun. Air conditioning and an electrical heating system were also installed in the original building Work was completed and the new facilities placed in service June 1 1957 at which time the air conditioning made it possible to schedule classes throughout the summer months

Effective January 1, 1958 the school became officially known as "The Plant and Engineering Training Center" (subsequently changed to The Maintenance and Operations Training Center) under supervision of a member of the General Office staff. The supervisor together with three Project Supervisors, also on the General Office staff, were assigned as resident instructors, with assistant instructors still furnished by the Areas when needed Instructors are no longer restricted to one phase of the work.

All study material is written by the resident instructors. Courses are being continually revised and rewritten to keep up with develop-

ments. New courses are added as new equipment is placed in service.

Ten-day Sessions Planned

Each course is outlined to require ten days. Apprentice wire and repeater technicians attend four ten-day sessions. Maintenance students attend one ten-day session. A course for maintainers can be made up of one or more Elements as required. An average of four classes per month are scheduled throughout the year, two in operations and two in maintenance. Two ten-day courses cover basic electricity, repeater and carrier equipment common to large and small offices. These two courses are given to maintenance and operations men alike, an arrangement which brings the two groups closer together, resulting in a better understanding of their mutual problems. The over-all results are better cable operation and greater efficiency.

Among other activities at the Training Center are Supervisors' conferences and PWS seminars. The seminars are conducted to acquaint sales engineers and representatives with the over-all operation of private wire systems.

The regular courses, which are listed in a brochure issued January 1, 1959 are known as Elements: for example, Element One (AMO) on d-c theory. The AMO is for (A) Automatic, (M) Maintenance, and (O) Operations. Special courses are scheduled from time to time as required. For example, classes in ticketfax, weatherfax and special ASR equipment are conducted.

Element One (AMO) covers basic d-c theory, electrical measurements and fundamental transmission circuitry. Of course, time does not permit a full coverage of d-c theory, therefore the examples used in this course are confined to circuits found in telegraph equipment and transmission systems.

Intricate mechanisms of teleprinters and control cabinets are studied by members of a maintenance training class

Maintenance laboratory at Chattanooga center is equipped for training practice in Telefax as well as printing telegraphy

Easy-to-follow "breadboard" wiring of circuit components facilitates laboratory instruction in teleprinter circuitry

Element Two (AMO) covers basic a-c theory, repeaters, advanced transmission circuits and fundamentals of carrier telegraphy. The equipment covered in this course is common to large and small offices. Here, the student is required to develop the schematics of all equipment covered, and explain the function of each component as applied to that particular piece of equipment. Upon the completion of Elements One and Two, the student should be able to analyze and understand circuit diagrams.

Circuits and Equipment Studied

During the laboratory sessions, the students are required to wire up all types of repeaters on lab-boards. This enables them to become thoroughly acquainted with the equipment studied in the lecture room. The repeaters so built up are placed in circuits and lined up properly. Working circuits also are set up in the operations laboratory and lined up according to specifications.

Various outstation selectors and other outstation equipment is available in the maintenance laboratory for training purposes. Here, too, the student studies the function of the individual components making up the various pieces of equipment, after which each piece is studied as a whole. Circuits are set up in the labora-tory so the actual operation of each piece of equipment can be observed.

Timing charts, a development of the Training Center, are used to give the slow-motion operation of selectors. By use of these charts the student is taught the sequence of operation of the individual components. The timing charts are also used in analyzing typical cases of trouble. Under the supervision of an instructor, cases of trouble are put in the selector. By the use of the timing charts, one group of students will lead another group step by step through the sequence of operation until the trouble is located. The students retain the charts for use on the job.

Up to and including December 31, 1958 a total of 2185 students attended 129 maintenance classes of 40 hours each. This represents 87,400 man-hours of training. During the same period, a total of 293 apprentice wire and repeater technicians attended 108 classes of 40 hours each, representing 46,880 man-hours of training. These figures, which do not include supervisory conferences and PWS seminars, demonstrate that the training effort is significant and should have increasingly valuable results as the effort is continued.

Reference

1. The Chattanooga Works, F. J. TRENT, *Western Union Technical Review* Vol. 6, No. 2, April 1952.

G. E. HOFFSTETTER has an impressive background of experience in Western Union operations. Starting as a Student Automatic Attendant at Columbus in 1918, he there became Automatic Attendant and Assistant Automatic Chief, then Automatic Chief and Chief Operator at Dayton, and later Division Traffic Inspector at Chicago and Operations Supervisor in the St Louis area. As General Operations Supervisor he was assigned as resident instructor to the Training Center at Chattanooga in 1956 and was placed in charge of it in January 1958. In connection with the training courses he has written many tutorial articles including "Simplified Explanation of Carrier Current Operation." Mr. Hoffstetter has been active in amateur radio for some 47 years and holds various radio licenses. He is a member of IRE and the American Meteorological Society, and is a Registered Professional Engineer.

RALPH R. GOSE, Assistant to Electronics Applications Engineer

Application of Commercial Voiceband Equipment to Microwave Telegraph Service

Whether to design new carrier terminal equipment as usual or modify an equipment type already in commercial production was the question. In this case adaptation of an available design to meet the Telegraph Company's rigorous requirements was the answer.

In April 1958 Western Union placed its MLD-4 Microwave Relay System[1] into service on the Pittsburgh-Cincinnati-Chicago circuit. The 4000-mc radio beam MLD-4 system that provides a transmission medium for as many as 48 voicebands loaded with carrier telegraph channels represents a substantial advance over former systems that could handle only 32 voicebands. One of the factors contributing to the success of this new system was the adaptation, herein described, of a commercially available carrier terminal which provided the necessary channelizing equipment for the required 48 voicebands.

Since it was urgent that this carrier terminal be installed at the same time as the radio equipment, an investigation was made to determine the most expedient method. This investigation revealed that up-to-date miniaturized equipment that could be adapted to Western Union requirements with a minimum of modifications was available from commercial manufacturers at reasonable cost. After considering the equipment produced by several of these manufacturers, a suitable supplier was located and Western Union engineers, in conjunction with the engineers of that firm,[*] made the necessary modifications to adapt that company's standard equipment to meet Western Union's requirements for the system.

Requirements

Based on experience with existing carrier systems placed in operation on beams between New York and Philadelphia,

[*] Lenkurt Electric Company, San Carlos, Calif

New York and Washington, Washington and Pittsburgh, and Pittsburgh and New York, during the years 1945 to 1948,[2] the following list of requirements was established prior to the development of the desired equipment; these requirements were met with varying degrees of success as will be described herein.

1. A frequency-division circuit design was desired that would permit a single voiceband, a 4-voiceband group, and either a 16-voiceband or a 32-voiceband group to be patched in the same manner as in existing Western Union carrier systems. These points in the circuit were deemed desirable patch points as the frequency and power levels thereat were compatible with existing systems, thereby facilitating growth, intersystem connections at drop-out, and diversity transmission (Since there was no commercial equipment available to match existing Western Union systems at any of the above-mentioned patch points, except for a single voiceband patch point, a system that provided patch points for a single voiceband, a 4-voiceband, a 12-voiceband, and a 24-voiceband group was accepted.)

2. At least 40 voicebands were to be provided by the frequency-division equipment and placed within a radio baseband width of approximately 200 kc. (For example, the spectrum could range from 10 kc to 216 kc or, if preferred, from 300 cps to 200 kc.)

3. Although the carrier equipment was to be designed to contain at least 40 voicebands, only 36 would be required initially on the Pittsburgh-Cincinnati-Chicago circuit. The remaining four voicebands could be used for spares or for growth between Pittsburgh and Cincinnati and Cincinnati and Chicago. Any group or groups of voicebands that could be dropped or transferred at Cincinnati would necessarily be related to the 4-voiceband

group, the 12-voiceband group, or the 24-voiceband group patch points. Transfer of groups smaller than four voicebands would be on an individual basis.

4. The equipment was to be mounted on standard 19-inch racks, each rack to have a maximum height of nine feet. However, in meeting this requirement the advantages of flexibility, electrical performance, and ease of maintenance were not to be impaired. Equipment on the racks was to be arranged so that the regular system could be built out to at least 40 voicebands. That is, since the regular system equipment turned out to have patch points at the single voiceband, the 4-voiceband group, the 12-voiceband group, and the 24-voiceband group, then similar equipment for the fallback system was built out only to the 12-voiceband group patching points. The fallback racks also provided individual voiceband frequency channelizing equipment for one 12-voiceband group.

5. Plug-in circuit components were desired to simplify operation and maintenance since such components would provide flexibility and lessen the amount of shelf spares required. With the fallback system equipped as planned, very few shelf spares would be needed

6. In addition to the jack field for the block patching points, other test points and jacks for entry into the circuitry were desired for simplifying line-up and maintenance procedures. Individual voiceband patch points on a 4-wire basis were to be supplied in a carrier switchboard remote from the racks, but some means was to be made available for connecting into the individual voiceband circuit to facilitate testing at the carrier system rack Jacks at the rack were also desired that would include all patch points from the high-frequency line jacks up to the 4-voiceband group patch point, inclusive. Bridging test points were to appear on some type of jack or socket, in convenient locations, for "in service" testing

7. Self-powered racks, operating off 115-volt 60-cps commercial power were specified in order to simplify installation. All fusing, including incoming office battery, power supplies, and regulators for variations exceeding plus or minus 5 percent were to be mounted either on the rack or near the power distribution panel.

8. The requirements for multiplex terminal equipment for each voiceband were to meet, in general, those stated in the RETMA

Standard Proposal No. 436, except that they were to apply to the multiplex equipment on a high-frequency back-to-back basis and not on a system basis. The requirements set forth in this proposal were to be met with the following exceptions in characteristics and transmission performance:

a. The voice-frequency channels were to be operated on a 4-wire basis with input and output impedances, 600 ohms balanced to ground

b. The voice-frequency channel input and output longitudinal balance was to be 50 db for the frequencies specified.

c. A 1000-cps voice-frequency channel test signal was to be applied at a power level of minus 16 dbm at the input to the 4-wire send circuit

d. The voice-frequency channel output power was to be capable of delivering plus 7 dbm with standard signal input, while satisfying the distortion limitations.

e. The voice-frequency signal-to-noise ratio was to be at least 60 db, unweighted, with all other channels idle.

f. The voice-frequency channel signal-to-noise ratio was to be at least 55 db, unweighted, with all other channels loaded with a signal tone at minus 26 dbm and at any frequency within the channel bandwidth.

g. The voice-frequency channel signal-to-noise ratio was to be measured by applying a minus 16 dbm signal to the input terminal of the channel and checking the channel output in the presence and absence of the test signal

h. The amplitude-frequency response characteristic of the voice-frequency channel was not to vary more than plus or minus 1 db, with 1000 cps as a reference, over the range of 300 to 3300 cps.

i. The harmonic distortion in the voice-frequency channel for the second or third harmonic of any frequency was to be such that the harmonics that fell within the bandwidth would not exceed 5 percent (26 db below the fundamental) when measured, using an input of minus 16 dbm, and this distortion was not to exceed 1 percent (40 db below the fundamental) when measured, using an input signal of minus 26 dbm.

j. Individual intermodulation products (a ± b, 2a ± b, a ± 2b, etc) between any

two frequencies (such that the products fell within the bandwidth) were to be at least 40 db below the combined level of minus 26 dbm when the two test frequencies were transmitted at levels of minus 29 dbm each

k. The harmonic distortion was to be measured by connecting an oscillator (inherent distortion at least 50 db below the fundamental and a nominal source impedance of 600 ohms) to the voice-frequency channel input terminals. Two such oscillators and a 600-ohm 3-way pad were to be used for the intermodulation measurement.

l. The frequency displacement for the voice-frequency channel was not to exceed 1 cps.

9. The input and output impedance of the high-frequency circuits of the frequency-division terminal equipment that connected the group of 40 voicebands to the radio baseband was to be 125 ohms, balanced to ground.

10. It was desired that the signal-to-peak interference ratio would not be less than 37 db (unweighted) when each of the 40 voicebands (loaded with 20 carrier frequency shift teleprinter channels) was transmitted through a radio system that contained 40 repeaters under 20-db simultaneous fading conditions in seven sections and with an allowance of 6 db for maintenance margin.

11. Facilities for individual voiceband regulation would be included.

12. Provisions would be supplied for interconnecting carrier supplies of individual systems should one supply fail.

13. Alarm facilities to detect system failure at the possible 4-voiceband group and other multiple voiceband groups, where a patch or transfer point was permitted, would be included. This equipment was to be on a plug-in basis.

14. Alarm facilities operating on a fail-safe principle for filament, plate, and signal circuit battery would be included.

15. A complete set of specifications necessary for ordering, installing, operating, and maintaining the carrier frequency-division system and all smaller components was to be furnished by the supplier of this equipment. The specifications were to include complete schematic and wiring diagrams for each rack, the equipment mounted thereon, and the interconnections between racks.

Modifications

Investigation revealed that most commercial equipment failed to meet Western Union requirements for one reason or another. Some reasons for rejection were (1) insufficient voice-frequency bandwidth; (2) failure to provide 40 voicebands in the 200-kc spectrum; (3) insufficient frequency stability; and (4) unsatisfactory frequency-division patterns. Consequently, when the most likely supplier was discovered, studies were made of that firm's equipment and specifications, and a special visit was made to the factory to learn their methods. In cooperation with that company's engineers, the equipment was assembled on the racks and, where necessary, modifications in circuits and components were made as required by Western Union.

This section is concerned with the equipment as it now exists in modified form, rather than with the actual "tearing down" or "building up" that was required to modify it.

The equipment was mounted on standard Western Union racks, 19 inches wide and 9 feet 6 inches high. Extreme flexibility was gained by wiring each rack in a similar manner so that, if some of the equipment panels required by original circuit design were to be omitted at a later date, or if in the future system circuit requirements were changed, the necessary equipment could then be added or the shelves replaced by new equipment without changing the rack wiring. This arrangement provided for many variations in equipment assembly and, as it turned out, for the 16 racks on the Pittsburgh-Cincinnati-Chicago circuit 12 different rack displays were assembled.

The first four racks, left to right (Figure 1), for the west terminal of Cincinnati illustrate the combinations of assemblies obtainable and demonstrate the flexibility of the standard rack designs in meeting various circuit assignments. (The fifth rack is the standard Western Union combiner rack.) The racks at the Pittsburgh and Chicago terminals are the same as those shown for Cincinnati except for slight modifications.

In addition to the two 12-voiceband fallback racks, a spare group of channelizing equipment for 12 voicebands was provided in the circuits on one of the racks, to be substituted for similar groups used regularly on the operating system. This equipment permitted release of the regular channelizing equipment for periodic

same 48 voicebands over two separate mediums.

At the receiving terminal the two receiving jacks, one from the regular and one from the fallback path, were located adjacent to the block receive jack for ease in selection of the path that was in working condition.
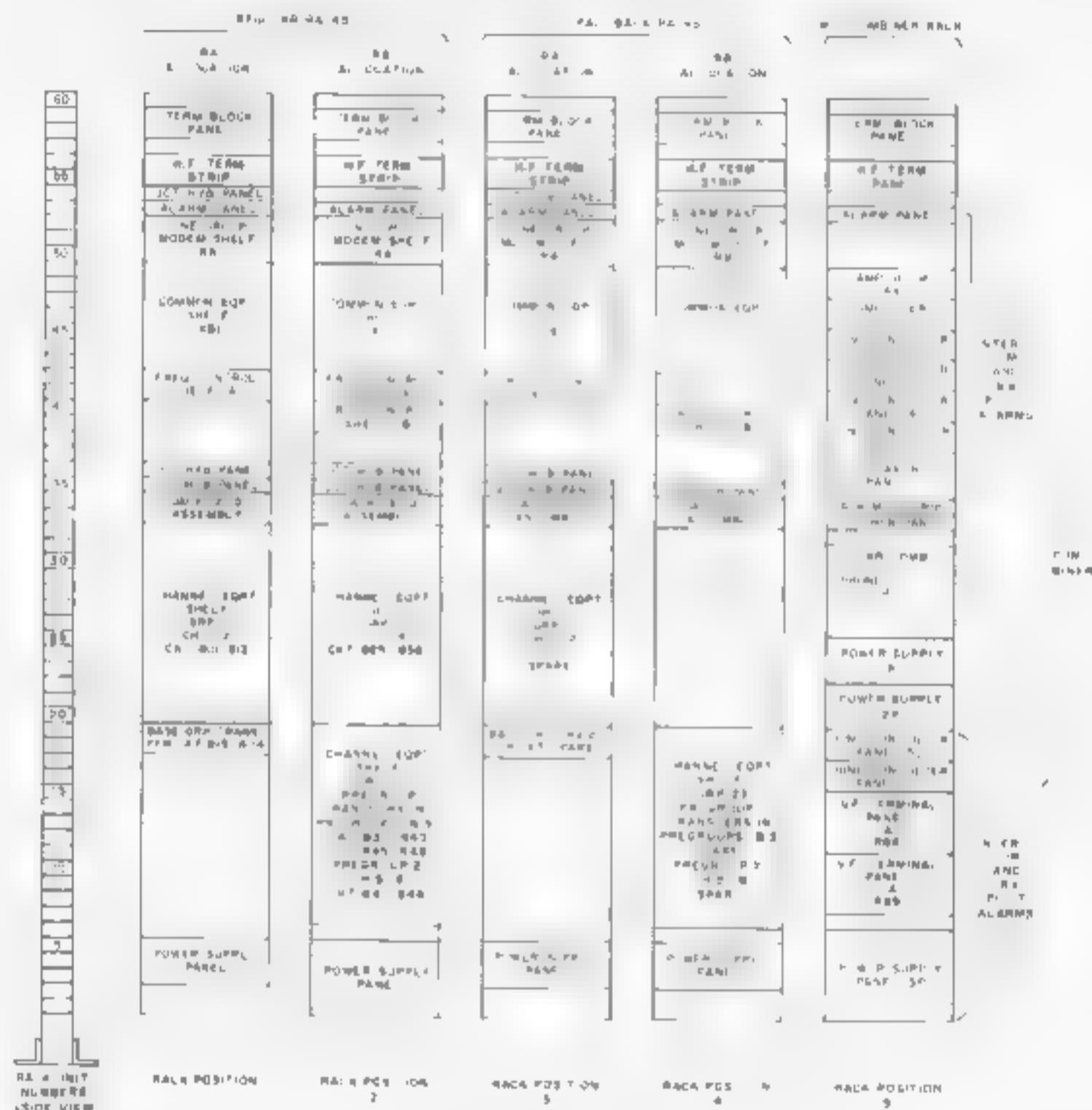
Figure 1. Rack display — Cincinnati — west terminal

routine maintenance or for substitution in the event of failure of the regular equipment.

One special feature included in the standard rack wiring was the junction hybrid transformer panels which permitted transmitting the signals from the

Plant Layout

Figure 2 is a photograph of the equipment at the Chicago terminal office The two cabinets and five racks, left to right, are as follows: the two cabinets are the faultfinding equipment associated with the

radio terminal, the first of the five racks is the Western Union combiner rack; the second, third, fourth and fifth racks are the frequency-division terminals (the last two of these racks furnish the fallback carrier system equipment). The balance of the radio equipment at both Chicago and Cincinnati (where a similar radio lay-
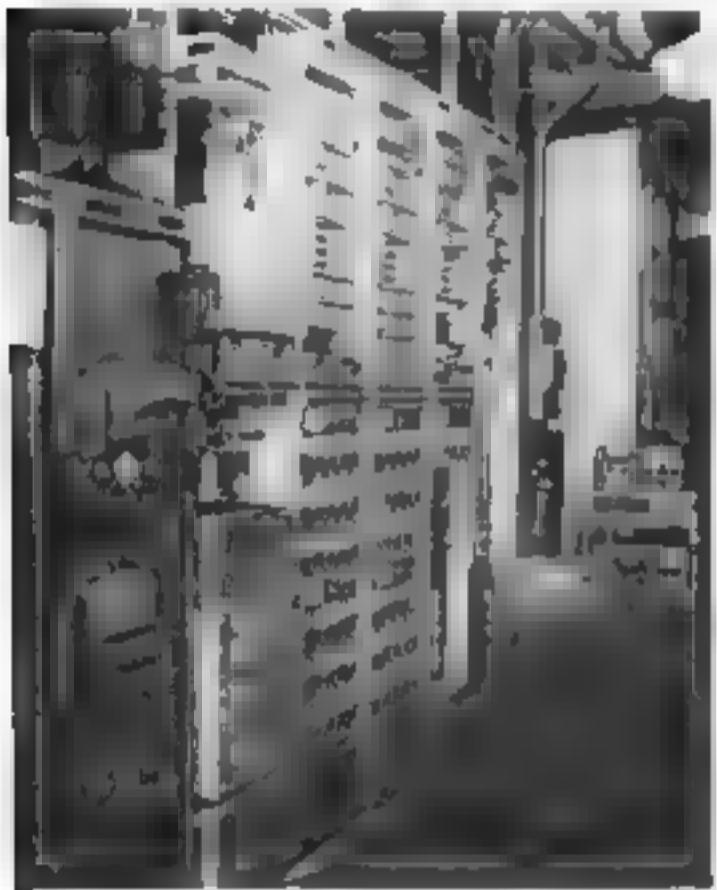
Figure 2. Equipment layout at Chicago office

out exists) is located in the tower of an adjacent building. The plant layout at Pittsburgh is somewhat different since both the radio and the carrier equipment are mounted in one location

Mounted on the test table which can be seen just beyond the teleprinter console is a test panel, an oscillator, a transmission measuring set,[3] and a frequency analyzer. These units comprise the major pieces of test equipment furnished for the operation and maintenance of the carrier terminals.

Frequency Translation, Sending

Figure 3 illustrates the circuit pattern used to combine the voicebands for transmission over the MLD-4 microwave relay system

Four 0.3- to 3.3-kc voicebands were first translated to form a pregroup in the 8.7- to 23.7-kc range, using carriers of 12, 16. 20 and 24 kc. Three of these pregroups were then translated to form a 12-voiceband base group in the 40.3- to 87.3-kc range, using carriers of 64, 80 and 96 kc Two of these base groups were then combined to form a 24-voiceband line group in the 40.3- to 139.7-kc range by translating one base group to the 92.7- to 139.7 kc range by means of a 180-kc carrier; the other base group remains unmodulated in the 40.3- to 87.3-kc range. Two of these groups were then translated upward in the spectrum; one group to the 164.3- to 263.7-kc range and the other group to the 344.3- to 443.7-kc range, using the lower and upper sidebands, respectively, of the 304-kc carrier. The two groups were again translated to form a 48-voiceband radio line group in the 12.3- to 215.7-kc range The 12.3- to 111.7-kc (RA allocation) and the 116.3- to 215.7-kc (RB allocation) portions were obtained using carriers of 276 and 560 kc, respectively

Frequency Translation, Receiving

At both the regular and fallback receiving carrier terminals the 48 voicebands are frequency-divided and demodulated (through a pattern reversed from that described for the sending terminal) to the 12-voiceband group spectrum of 40.3 to 87.3 kc, as shown in Figure 3 From this patch point, the regular equipment frequency-divides and demodulates the channels. translating each of them to its original 0.3- to 3.3-kc voice-frequency band. Should the regular base group and line group carrier equipment fail, the local channel frequency-division equipment may be patched to the fallback jack at the 40.3- to 87.3-kc spectrum for 12 voicebands

Frequency Control Circuits

For satisfactory operation of Western Union's frequency-modulated telegraph channels, any voiceband must have a frequency stability within one cycle To provide such stability in bands or systems in tandem, the manufacturer modified his

Figure 2. Frequency translation — block diagram

standard equipment to include frequency control of the 12-, 16-, 20- and 24-kc carriers for each receiving voiceband unit.

The frequency sources at both sending and receiving terminals are highly stable, independent, temperature-controlled crystal oscillators for 96, 180, 304 and 276 or 560 kc. The 12, 16, 20, 24, 64 and 80 kc are derived from the 96 kc.

Frequency control involves the transmission of a control frequency (16-kc) through the various stages of modulation from the sending pregroup over the system to the receiving pregroup. This frequency is used by the receiving equipment at the distant terminal to correct for any frequency shift that might occur in the signals as they pass through the sys-

tem, thereby establishing a frequency stability throughout the entire system to within one cycle in each voiceband. The 16-kc control frequency is received at a level of minus 17 dbm at the 4-voiceband point (pregroup), where it is combined with a frequency of 4 kc from the local 96-kc transmitting supply to obtain the 12-, 20- and 24-kc demodulating carriers in each receiving voiceband associated with a particular 4-voiceband group.

The 4-kc frequency is produced in a balanced modulator from the 20 kc and 24 kc of the local carrier supply This 4 kc is then combined with the 16-kc control frequency received over the radio beam (in another balanced modulator circuit), thereby producing the 12 kc and 20 kc for channel 1 and channel 3 receiving demodulators, respectively, of the 4-voiceband group. The 20 kc is also combined with the 4 kc in another balanced modulator circuit to produce the 24-kc demodulating frequency for channel 4. The 16-kc control frequency is used directly to demodulate channel 2

Any frequency shift introduced by the system varies the 16-kc control frequency Since this frequency is applied directly to the channel 2 receiving demodulator, a frequency error in this channel cannot occur. As long as the 96-kc oscillator at the receiving terminal's local carrier supply remains matched exactly with that at the distant transmitting terminal, any variation in the 16-kc control frequency is reflected in the demodulating carriers for receiving channels 1, 3 and 4, in proportion to the relation of the 12 kc, 20 kc and 24 kc, respectively, to the 16-kc control frequency. This arrangement compensates for any possible frequency drift between transmitting and receiving terminal supplies.

Voiceband Equipment, Input and Output

Each voice-frequency channel unit, as manufactured by the supplier, usually comes equipped with a standard plug-in unit containing a resistance hybrid and pad This unit, normally used in telephone circuits, was modified to meet Western Union's carrier telegraph requirements

for 4-wire transmitting and receiving voicebands as listed below

1. To coordinate the signal levels of the commercial voiceband channelizing equipment with Western Union's standard voiceband signal level of minus 7 dbm, the transmitting and receiving pad values in this plug-in unit were changed to 16 db and 4 db. respectively. This standard signal level of minus 7 dbm is transmitted and received from the voiceband channelizing equipment and represents the aggregate rms level of 20 carrier telegraph channels for one voiceband.

2. To maintain the necessary longitudinal balance at both the sending and receiving sides of the voiceband, an isolating transformer was mounted in the plug-in unit and inserted in the circuit ahead of the 16-db unbalanced pad on the sending side The output transformer of the channel amplifier and the low-pass filter preceding the 4-db pad provided sufficient longitudinal balance on the receiving side to meet Western Union requirements.

Each voice-frequency channel unit normally comes equipped with a voice-frequency plug-in filter that cuts off below 3.3 kc. To broaden the frequency response of the voice-frequency channels to the 0.3- to 3.3-kc range required for telegraph service, a 3.4-kc plug-in filter was substituted. A highly satisfactory frequency response over the entire system, with a variation of only a fraction of a db over the specified range, was obtained through the use of this filter

Combiner System

In Western Union systems prior to the development of the combiner, transmission of 4-voiceband or 8-voiceband groups over two parallel beams permitted the receiving terminal attendant, in the event of beam or carrier equipment failure, to select these individual voiceband groups from either beam without contacting the transmitting terminal to coordinate switching time. Each terminal was equipped with a duplicate set of frequency-division carrier multiplexing equipment for groups of 4 or 8 voicebands (fallback equipment) that, except for the omission of individual voice-frequency channelizing units, was the same as that used with the regular beam. The 150-kc

baseband on the regular and the alternate (fallback) beam routes was divided into 16-voiceband groups which, in turn, were divided into 8- or 4-voiceband groups. Since these groups were available for patching, the attendant could select individual voiceband groups on the regular or the fallback route, whichever was in the better working condition, with a minimum of outage time. In addition, the 4-voiceband groups could terminate at different destinations and each could travel over different beams; this arrangement always provided an alternate route over which the same 4-voiceband group could be received. This method of patching provided service with a minimum of outage time since the circuit could be switched immediately and the maintainer could use whatever time was necessary to find and replace the component in trouble, either at the carrier terminal office or elsewhere in the beam system.

A similar arrangement of fallback equipment for minimizing outage time and facilitating maintenance was required for the adapted commercial equipment. The pattern of modulation set up for the equipment provided pregroup transfers of 4 voicebands and base group transfers of 12 voicebands. Because of the design characteristics of the equipment, the 12-voiceband group was selected as the most suitable for transmission of signals over the regular and alternate beam systems, allowing the receiving terminal attendant a choice of two carrier systems (regular and fallback) in case of beam failure or carrier equipment failure up to the 12-voiceband patch point.

The introduction of the combiner to derive the best possible signal from the combined outputs of two beams, operating in parallel, altered previous maintenance and operating procedures. This combiner combines the two beams in parallel between the sending and receiving terminals at the 48-voiceband patch points (12.3- to 215.7-kc baseband).

Since the combiner combines only the radio equipment between two terminals for the two beams and not the 12-voiceband carrier terminal equipment, it eliminates patching at the 12-voiceband point

at the receiving terminal in the event of beam failure but does not eliminate patching at the 12-voiceband point for carrier equipment failure. As a result, the fallback frequency-division multiplexing equipment down to the 12-voiceband patching point is now used primarily as spare terminal equipment.

Generally speaking, failure can take place in one of, or in a combination of the following three areas: video cable or beam equipment, combiner equipment, or carrier equipment. In the event of *video cable or beam* failure (indicated by the 2.8-kc pilot alarm and intercom) at the combiner, the attendant can throw the appropriate switch so that only the signal from the path that is in operating condition is received until the failed beam is restored to service. When the video cable or beam failure is cleared, the attendant would then return the switch to its normal position so that the signals can be received from both paths. Should the failure be in the *combiner*, the attendant can patch it out of operation at the combiner rack. He can then, if necessary, select the better of the two paths at the 12-voiceband patch point as described previously. In the event of *carrier equipment* failure, the fallback equipment can be patched into the circuit at the single voiceband, the 12-voiceband, or the 48-voiceband patch point, as required, or shelf spares (which may or may not be plug-in units) can be substituted for the failed components. Since many factors must be taken into account, the fallback equipment to be patched or the spare equipment to be substituted in the circuit is dictated by the circumstances existing at the time of failure.

It should be noted that in previous systems without a combiner the receiving terminal attendant could immediately do the necessary patching to the fallback route, whereas with the combiner in the system the nature and location of the trouble, wherever it may be in the system, must be known first before any switching or patching can be done.

Combiner Circuits

The group of 48 voicebands (12.3 to 215.7 kc) is passed through a junction

hybrid transformer at the sending terminal and through two identical junction filters into two 1-mc radio modulators (one for each beam) to be transmitted over two parallel radio beams (paths A and B) to the distant carrier terminal as shown in Figure 4. The signals which are transmitted over these two paths contain the same intelligence, are sent in parallel, and are in the proper phase relationship. The spectrum from 0.3 to 3 kc is available at each junction filter for transmitting speech from the intercom and the 2.8-kc alarm tone over each beam. The frequency spectrum from 4 to 8 kc is not used for transmission of intelligence but is available at the receiving terminal to sample the noise on the circuit.

The signals are received from both beams at the receiving terminal through two 1-mc radio demodulators (one for each beam) and are passed through two junction filters.

As indicated in Figure 5, the intelligence from each beam, which is identical, is contained in the 12.3- to 215.7-kc portion of the frequency spectrum. This portion of the spectrum is picked off by two separate band-pass filters (one for each beam) and is applied to separate constant current amplifiers (combiner amplifiers A and B). The output of the constant current amplifiers is combined in phase to produce a common signal. A second set of band-pass filters selects an idle portion of the spectrum (4 to 8 kc) from each baseband. Any noise that occurs is amplified by the noise amplifier which, in turn, controls its associated combiner amplifier.

When a fade or failure occurs on one beam (path A, for example), the noise as observed in the 4- to 8-kc portion increases; the noise amplifier produces a higher value of bias voltage which is applied to combiner amplifier A. This increase in bias voltage reduces the current in the tube circuit of the combiner amplifier.
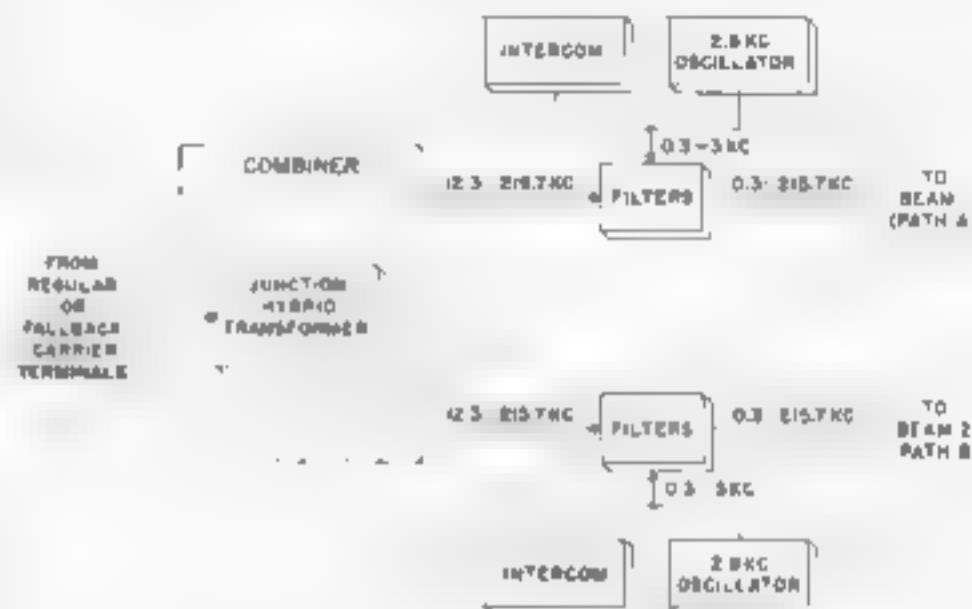
Figure 4. Combiner rack — sending — block diagram

fier. However, the constant current source keeps the total current constant by causing an increase in current (which is almost equal to the current loss of combiner amplifier A) in the tube circuit of the
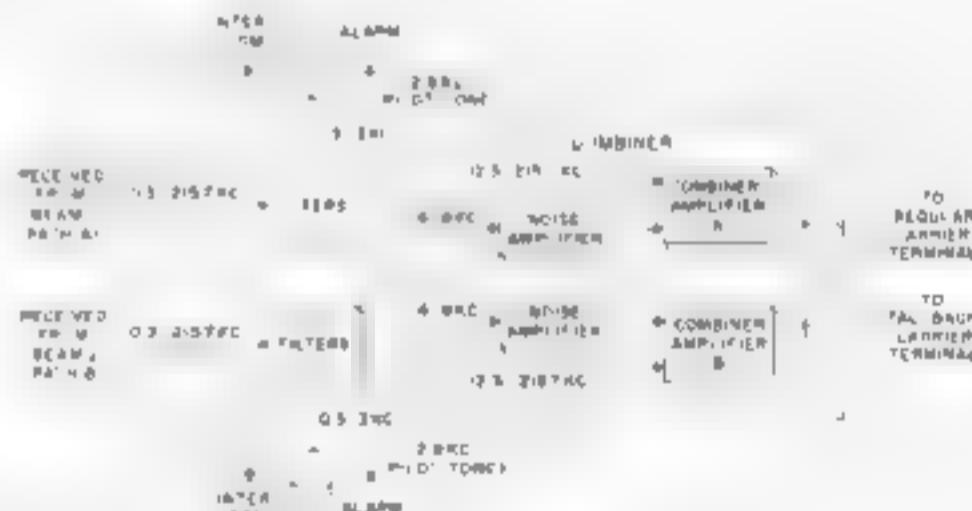
Figure 5. Combiner rack — receiving — block diagram

combiner amplifier for path B. This, then, reduces the gain of path A, which is fading, and increases the gain of path B. As a result, a constant output signal level is maintained.

The outputs of the two combiner amplifiers are combined in phase through a common output transformer associated with the combiner circuits. The output signals from this transformer are fed simultaneously to the regular and the fallback receiving carrier terminals. It should

with two separate speakers. The 2.8-kc pilot tones traverse independent beams from the input of the 1-mc modulator to the output of the 1-mc demodulator When either tone fails, an audible alarm is activated and an alarm lamp is lighted to indicate which beam is at fault.
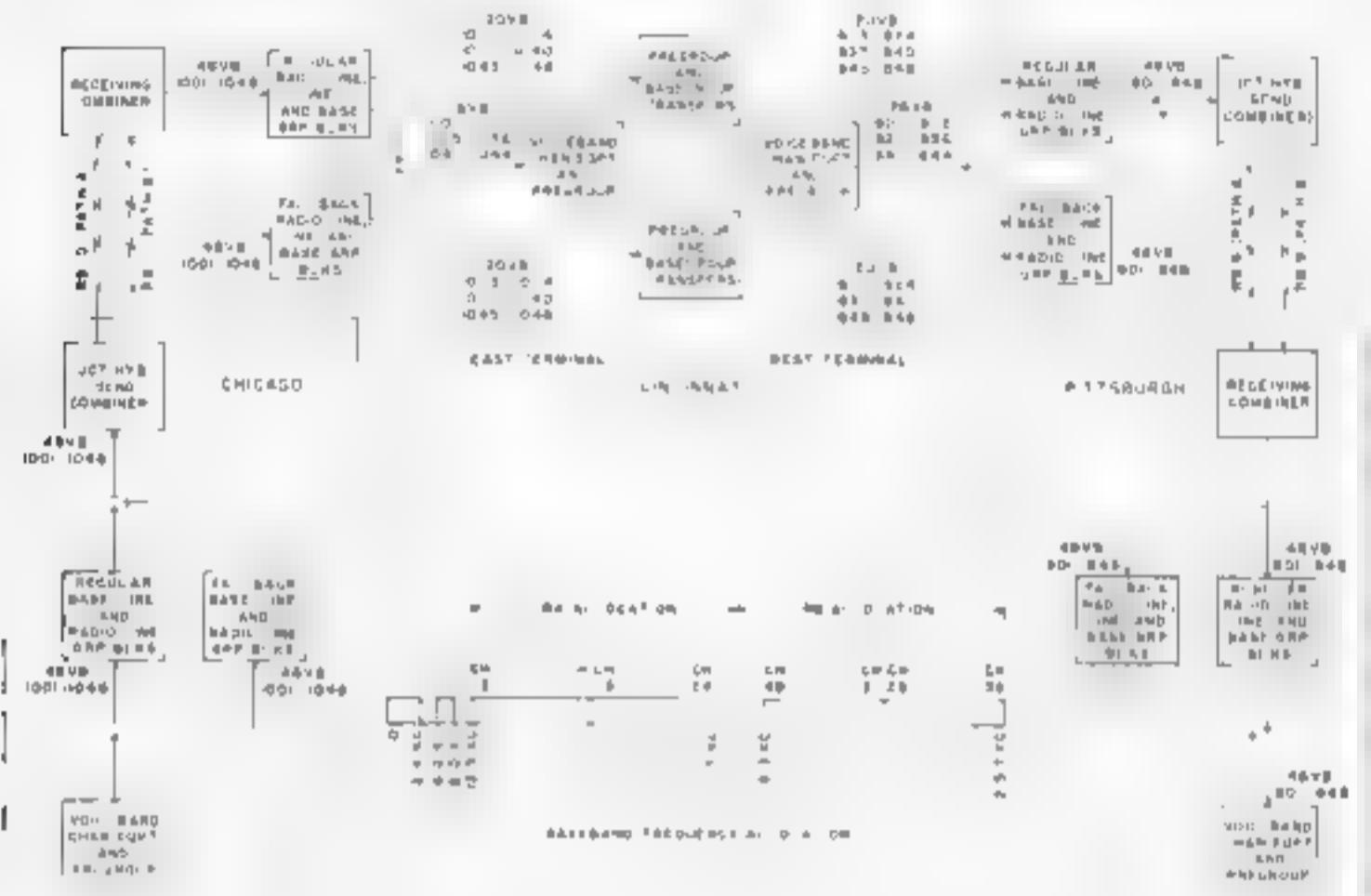
Figure 6. Traffic flow pattern — system block diagram

be noted that because of phasing problems the combiner was found to be useful for the radio portion but not practical for the carrier portion of the system. This is due to the necessity for the same signals to be transmitted over the two systems in parallel so that they will be in exact phase at the receiving terminal for minimum distortion.

The band of frequencies from 3 to 12 kc is received from each radio beam independently since the beams are not in combined use for this spectrum. The frequencies below 3 kc are used as pilot channels for speech on the intercom and for the 2.8-kc pilot alarm tone. The speech may or may not be combined from a single phone transmitting at the sending terminals but is received from each beam independently and amplified for connection

Intermediate Drop-Out and Transfer

Cincinnati is an intermediate point in the Pittsburgh-Cincinnati-Chicago system and acts as an east terminal for some voicebands, a west terminal for others, and either as a repeater or a transfer point for the remaining voicebands.

Figure 6 shows the transmission of only eastbound traffic from Chicago to Cincinnati, Chicago to Pittsburgh, and Cincinnati to Pittsburgh. Transmission of westbound traffic between these destinations is accomplished in a similar manner.

Moving east from Chicago, identical traffic is sent over two parallel beams (RB10 and RB11) to the receiving combiner at Cincinnati. The receiving combiner combines the two signals and derives a common output that is sent to the regular and fallback channelizing terminals. At this point, 28 of the

48 voicebands that contain traffic destined for Cincinnati are dropped out and terminate in voiceband channelizing equipment. The remaining 20 voicebands that contain traffic for Pittsburgh are sent through the transfer circuits to the sending combiner. Twelve of these 20 voicebands are transferred through a 12-voiceband base group transfer unit and the remaining 8 voicebands are transferred through two 4-voiceband pregroup units.

At the sending combiner rack, 28 voicebands containing traffic that originated in Cincinnati and is destined for Pittsburgh replace the 28 voicebands in the frequency spectrum that were dropped at Cincinnati. The 28 voicebands for Pittsburgh are grouped with the 20 voicebands from the transfer circuits. The 48 voicebands are then transmitted through the sending combiner and over two parallel beams (RB8 and RB9) to the receiving combiner at Pittsburgh.

The 48 voicebands at Cincinnati, sent to the fallback channelizing equipment from the receiving combiner for beams RB10 and RB11, contain the same information that was sent to the regular channelizing equipment. Should the regular receiving base group and line group carrier equipment fail, the information from the fallback equipment can be transferred to the regular frequency channelizing terminals and to the regular pregroup and base group transfer equipment at the receiving 12-voiceband patch point (40.3 to 87.3 kc).

The 20 voicebands that were transferred through and grouped with the 28 voicebands that were picked up at Cincinnati are sent to the sending combiner over the regular base group and line group equipment. This same information is sent over the fallback sending equipment and fallback base group and line group equipment and is available at the fallback send jack. Should the regular sending base group and line group carrier equipment fail, the information available at the fallback send jack can be patched to the sending combiner and transmitted in parallel over beams RB8 and RB9 to the receiving combiner at Pittsburgh.

It should be noted that in the event of pregroup or base group transfer equipment failure, spare pregroup or base group transfer equipment can be substituted by direct patching to the associated equipment.

When the first over-all performance tests were made on voicebands from Pittsburgh through Cincinnati to Chicago, it was found that two voicebands through the pregroup transfers could not be operated in telegraph

service. This was because the filtering in the base group transfer units was not adequate for the particular system arrangement of base group and pregroup transfer units as applied at Cincinnati. As a result, the base group transfer unit was redesigned to obtain satisfactory results.

Video Cables

Since the radio 1-mc modulators and demodulators at Cincinnati and Chicago were not installed in the same building as the carrier terminal, it was necessary to route the baseband frequencies from one location to the other through two independent cables (cables 1 and 2). A circuit pattern for assigning cable pairs (paths A and B) in each of these cables was worked out to reduce possible outage time to a minimum, keeping in mind that Cincinnati was an intermediate point with 20 voicebands passing through transfers.

Figure 7 shows the cable-pair connection pattern for video cables 1 and 2; the directions through the cables, like the directions through the beams, are independent. The circuitry assignment divides not only path A and path B beams between the two cables, but also the sending and the receiving functions; consequently, the failure of one cable affects only one direction of transmission through the 4-voiceband and 12-voiceband transfers at Cincinnati. The alternate route for that direction is readily available through the alternate carrier circuits by way of the remaining cable. With this arrangement, the use of solder connections instead of jacks at the end of the video cable would cause no delay in the restoration of service.

Since the path B circuits duplicate the path A circuits throughout the parallel radio system, the attendant can promptly switch or patch individual voicebands or groups of voicebands at the carrier racks, as required, to restore the message circuits in the event of carrier failure, thereby reducing outage time to a minimum. The fault can then be located and cleared.

Since the loss of the 48-voiceband group, indicated by the loss of the 2.8-kc tone on either path, can be due to either a beam or a video cable failure, the attendant must determine which equipment is at

fault. The operating procedure is the same as described for beam failure: at the combiner rack, the attendant would throw the appropriate switch, determine whether the video cable, the beam, or both were at fault, and would take the necessary steps to rectify this trouble condition.

It is advantageous in low-level circuits that carry many voicebands to keep to a

since the carrier and radio terminals are in the same office and rack row.

3550-Cycle Regulator Tone and Pilot Alarm in Each Pregroup

The commercial voiceband channel units for telephone service normally are equipped with plug-in units for a 3550-cycle regulator tone circuit to regulate the output level of the receiving channel unit
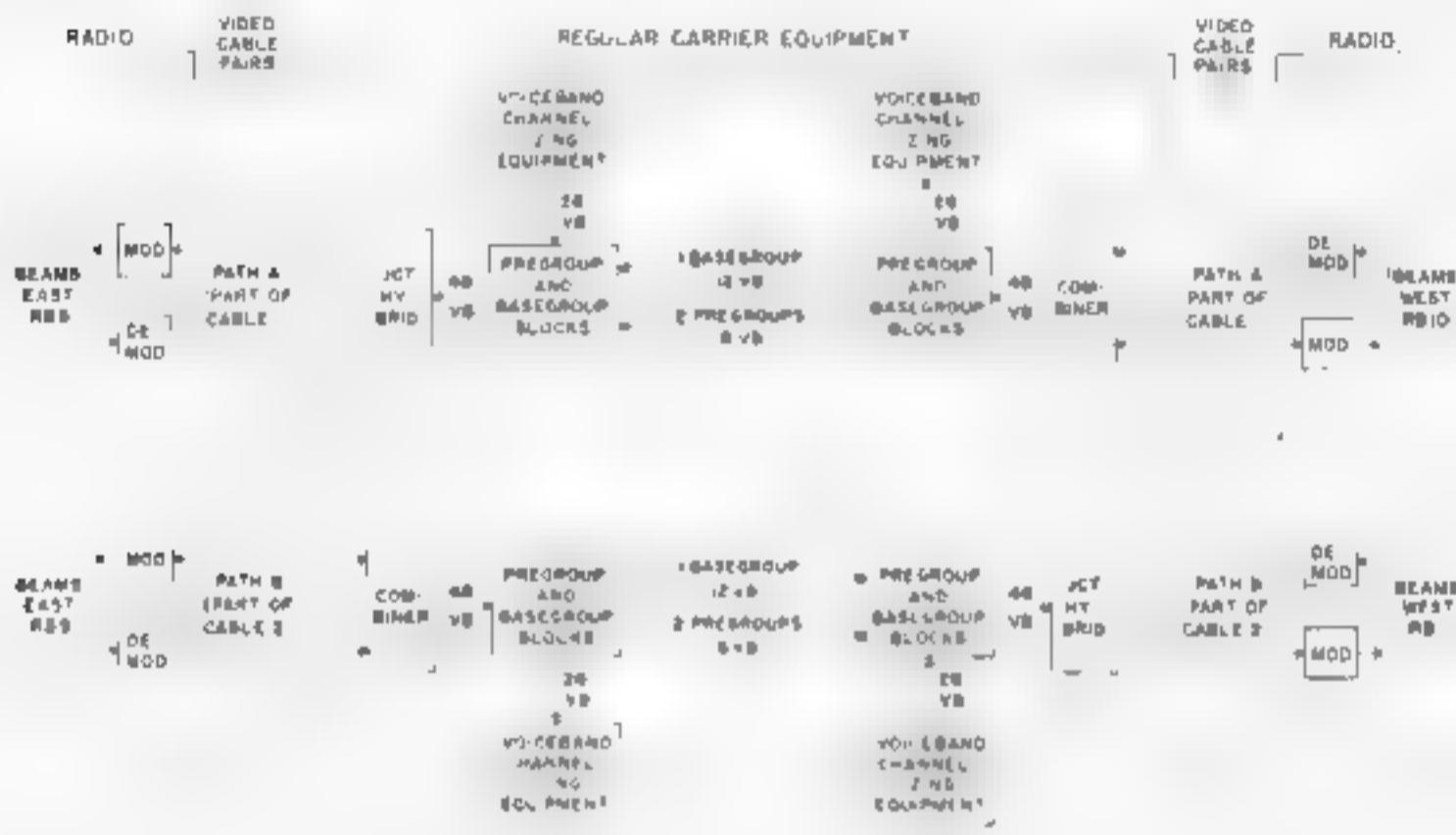
Figure 7. Cincinnati — block diagram showing video cables

minimum the number of sliding connections such as jacks and cable connectors. For this reason, the junction of the video cable and office pairs is a solder connection. The junction is similar to a distributing frame; all spare pairs in the video cable terminate at this junction point. The spare pairs might have been extended to the combiner racks and terminated in jacks for trunking to any system, but this would add more jacks or sliding connections in the system. For this reason, the cable connections in the radio cabinets in the tower are made directly to the terminal blocks for the modulators and demodulators.

A similar arrangement of video cables is used at the Chicago terminal. At Pittsburgh, no outside cables are necessary

This 3550-cycle tone is also frequency-modulated to carry ringing circuit signals.

The 3550-cycle tone, when used as a regulator, controls the automatic level regulator of the receiving voice channel terminal unit so that the received telegraph signal level remains constant. This regulator has a control range of plus or minus 7 db. It is transmitted through the system at a level 7 db below that of its associated telegraph load of 20 channels.

Since ringing circuits are not required for telegraph service, these circuits are used to provide a pilot alarm tone on one of the four channel units in each pregroup which, in effect, provides a pilot alarm tone not only for that channel but for the pregroup as a unit. Thus pilot alarm tone detects the loss of the signal over the whole system, including the voice channel transmitting unit and the voice channel

receiving unit. To accomplish this, one voice channel in each pregroup (channels 1, 5 and 9) is equipped with an independent oscillator (3550 cps) at the sending end and a plug in discriminator and relay unit at the receiving end. This relay at the output of the discriminator is biased to detect the presence or absence of the 3550-cycle tone. If the tone is absent, both an audible and a visual alarm are activated to indicate that a failure condition exists. In addition to its function as an alarm, the 3550-cycle tone also regulates the output level for the associated channel. Since the remaining three channels in each group require the 3550-cycle tone only for regulation, a common 3550-cycle source (located on the common equipment shelf) is used to supply these channels in both base groups.

Alarm Circuits

Figure 8 shows the alarm circuits for the combiner rack and one of the four commercial equipment racks. It should be noted that the alarm circuits for all four commercial racks are identical to rack No. 1, shown in the drawing. This figure also shows the interconnections between the four commercial racks and the combiner rack on which the common alarm signals, visual and audible, are mounted. A chime is used to distinguish this audible alarm from other office alarms. This common alarm signal is provided to indicate one of the following types of failure on any of the four racks: (1) fuse failures for various panels mounted on the rack, (2) loss of the 3550-cycle pilot alarm tone in each pregroup; and (3) loss of system signals at the 12-voiceband group.

In addition, the common alarm signal is also activated when the 2.8-kc pilot alarm tone from either beam (path A or B) is lost, as indicated by the associated alarm circuits on the voice-frequency panels mounted on the combiner rack.

The power supply mounted on the combiner rack provides battery (plus 130 volts dc and 25 volts ac) for the common alarm signal and for the dry contacts on the four commercial racks that activate this signal. Any fuse failure in this supply

is indicated only by an associated lamp that is mounted on the power supply panel.

The power supply mounted on the commercial rack is somewhat different from the one mounted on the combiner rack as both the associated indicating lamp and the common signal alarm are activated to indicate a fuse failure for either the plus 130 volts dc or the 25 volts ac.

The pregroup alarm circuits, shown on the pregroup pilot alarm panel and in the channel units in the base group shelf, are new alarm circuits specially provided for Western Union telegraph service.

The rack alarm cutoff circuit on the common equipment shelf was modified so that all alarm relays on the rack would operate through this circuit. In the event of a trouble condition, the alarm cutoff switch associated with this circuit can be operated to render all alarm circuits for the rack inoperative until the trouble condition is cleared; thereupon, the alarm cutoff switch is returned to its normal position. The common rack alarm reset button should then be depressed, returning all alarm circuits on the rack to their normal operating condition.

Specifications

A complete set of specifications for the equipment was furnished which, augmented by the specifications drawn up by Western Union engineers, provided all necessary details for the operation and installation of the equipment at each office.

Load Tests

The idle signal-to-noise ratio for the carrier terminal alone ran 46 to 50 db on a flat meter or better than 50 db for weighted meter measurements.

When all 48 voicebands were loaded with 20 carrier telegraph channels, the signal-to-noise ratio plus cross talk in any idle voiceband ran about 3 db higher than idle noise alone. Over the beam system, idle signal noise in the voicebands was 40 to 45 db, noise plus cross talk being 5 db higher in level. These load results under
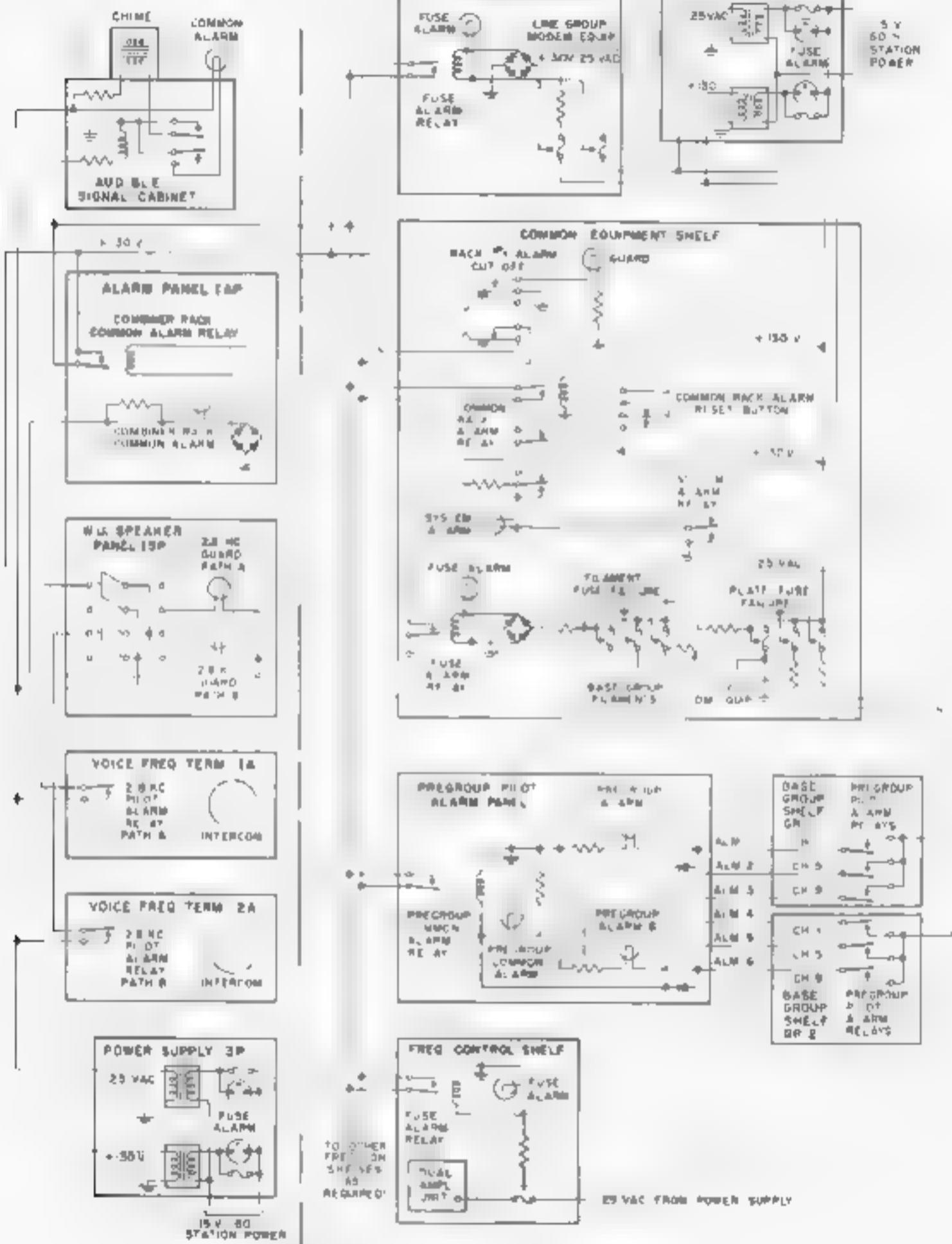
Figure 8. Alarm circuits — schematic diagram

operating conditions for 960 carrier tele-graph channels over a beam with 21 beam repeater sections were regarded as highly satisfactory.

*　　　*　　　*　　　*　　　*

In general, most of the requirements initially established were met and the equipment gave satisfactory results without any need for modification. In some areas, however, modifications were made so that the equipment could satisfactorily meet the requirements for telegraph service. Upon completion of the installation of the commercial carrier terminals, a series of field tests indicated the need for still further modifications. When these were completed the equipment was placed into service on the MLD-4 microwave relay system where it is operating in a most satisfactory manner.

The author wishes to acknowledge the invaluable assistance of Arnold E. Moser of the technical writing section who aided in the preparation of this article, as well as the contributions of all engineers who assisted in making the application of this carrier equipment successful. These engineers aided in the planning, modification, and recommendations for purchasing of the equipment, and made many engineering tests in the field. They also helped greatly in the preparation of the special specifications required for the installation and operation of the equipment. In particular, grateful acknowledgement is made for the contributions of the Lenkurt Electric Company and to all of their engineers who participated in this project.

References

1. THE WESTERN UNION MLD-4 MICROWAVE RELAY SYSTEM, J. J. LENEHAN, *Western Union Technical Review*, Vol. 13, No. 2, April 1959.

2. RADIO RELAY CARRIER IMPROVEMENTS, R. R. GOSE, *Western Union Technical Review*, Vol. 11, No. 2, April 1957.

3. TRANSMISSION TEST SET, R. R. GOSE, *Western Union Technical Review*, Vol. 10, No. 1, January 1956.

RALPH R. GOSE graduated from Virginia Polytechnic Institute and joined the Research Division of Western Union early in 1930. His activities there included studies of various phases of direct-current, carrier and telephone signal transmission. In 1943 he became associated with the newly organized Applied Engineering Department in charge of field applications of carrier systems for leased voiceband, wire line and radio beam. The present wire line E System, 10-Channel Terminal Bay for voicebands and WN Carrier Systems on the radio beam are part of these applications. Mr. Gose is presently supervising a carrier group engaged in combining standard carrier apparatus in new ways to meet new service demands. He is a member of AIEE.

INDEX

SUBJECT

INDEX (Continued)

SUBJECT

AUTHORS

INDEX (Continued)

AUTHORS